ELECTRICIAN'S HANDY BOOK

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ELECTRICIAN'S HANDY BOOK

A MODERN BOOK OF REFERENCE

A condensed cyclopedia of electricity, more exhaustive than an electrical dictionary, and serving the purpose of an electrical engineer's reference book, in which the general principles are fully treated in an elementary manner.

A reference book for the advanced electrician and a text book for the student.

BY

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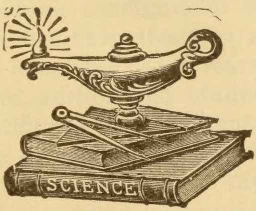

FIFTH REVISED AND ENLARGED EDITION

Illustrated by over 600 illustrations and diagrams

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PREFACE TO THE FIFTH EDITION.

The Electricians' Handy Book has met with such favor from its readers in the past that it is hoped that a new and enlarged edition will meet with the same kind reception. Since it first appeared many changes have taken place in the electrical field, and it is believed that the new matter in the work covers the field of new discovery and development. The present work is rather practical than theoretical; the abstruse theories of the subjects treated in it are not within its scope.

The work of treating the whole immense field of electrical engineering from early days to the present time would certainly be an endless one; the work of writing the present book has been lightened by the fact that the progress of electrical science in its practical aspect has been in the direction of the survival of the fittest. This tendency has had the effect of removing from the field of engineering many most ingenious devices, whose consignment to oblivion might be a subject for regret. But this disappearance of the old makes the amount to be described and learned less, and thereby lightens the labor of author and student.

It is fair to say that the development of electrical engineering is largely in the direction of simplification. In early days results inferior to those attained in the present era were secured by the use of apparatus more elaborate than that which is now employed. The evils of complication have long been recognized, and the trend of invention has been to avoid it. One of the earliest objects of the inventor was the production of an arc lamp without mechanism; the results of these efforts have completely disappeared from view, and the simplified mechanical arc lamps of the present day are their successors.

The same history can be traced for other branches of the science. Quantities of the most ingenious inventions are no

longer in use, as better machinery has taken their places. For electrical engineering is nothing if not practical, and sentiment has no part in dictating what shall survive and what shall be forgotten.

Something remains to be done in the elucidation of the theory. The very name of the science has never been adequately defined, although the working theory has been developed to a high degree of perfection. The greater general familiarity with the mere names of things electrical makes the subject seem less mysterious than formerly, when the words "ampere," "volt," and the like were rarely heard outside of a college. This should not induce the student to feel that his path is any shorter than was that of his predecessors. It is a much longer one, made a little easier by the fact that it is now a better-marked one. But he has more to learn than had his predecessors, and it must be more exactly learned. The modern science cannot be trifled with.

This book is sent on its way with the fullest sense of the difficulties involved in its preparation. In its writing the literature of the science and the classics of engineering literature have been freely used. The author's thanks are also due to many friends for assistance most kindly rendered.

OCTOBER, 1919

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Electricians' Handy Book.

CHAPTER I.

MATHEMATICS.

Electrical Calculations.—Electrical engineering involves in its practice much calculation. In the development of the theory of the science, the higher mathematics are employed; but in the more practical work of the science, and even in the study of its elementary theory, a slight knowledge of algebra and arithmetic is sufficient. Algebra is often regarded with dread, but if it is realized that algebra saves time and trouble and is easier than arithmetic in many cases, and that it provides a short road where arithmetic supplies a long one, it will be more favorably regarded.

The object of such a book as the present is not to teach arithmetic or algebra. The reader will find some points noted under both heads which may be of interest. But in algebra the "four first rules," as they are called, addition, subtraction, multiplication, and division, and the transformations of simple equations, and something of the theory of exponents, should be learned. Ohm's law is awkward for one to work with who is totally ignorant of algebra. The simple rules for elementary calculations are expressed in algebra far more concisely than in words. Ratio and proportion, the old "rule of three," given in geometries as well as in algebras and arithmetics, is of value.

Algebra.—The word "algebra" has a tendency to inspire the idea of difficulty and complication. This should not be so. Algebra is a system of short methods of attaining results, and

can be used extensively and to great advantage in electrical work by those who only know its four first rules, and the transformations and solution of simple equations.

The first law of electrical science that the student has to learn is Ohm's law. This law states that current strength is equal to electromotive force divided by resistance. This may be more concisely written thus:

$$\text{Current strength} = \frac{\text{Electromotive force}}{\text{Resistance}}$$

Let a symbol be assigned to each of these quantities. Call current strength, I, electromotive force E, and resistance R; the law can then be written thus:

$$I = \frac{E}{R}$$

Three letters express a whole line or more of print. The last expression is an algebraic equation. It is evident that by using algebra to express a law much time and trouble may be saved.

A quantity, such as 2 or 4, or it may be symbolized as A, can always be written as a fraction, without affecting its value. Thus these three quantities can be written:

$$\frac{2}{1} \quad \frac{4}{1} \text{ and } \frac{A}{1}$$

The use of unity as the denominator does not change their value. If the transformations of algebra are applied to an equation expressing a law, the extent of the law will be more fully grasped than if a bare statement of it is taken. The dividing by unity is often useful. Ohm's law can be written thus:

$$\frac{I}{1} = \frac{E}{R}$$

This equation can be read as a proportion or expression in the "rule of three," as it used to be called. It would read:

$$I : 1 :: E : R$$

This proportion states that if the current strength exceeds unity, the electromotive force must exceed the resistance, and the reverse. If the proportion is to be written out at full length it

would read: the current strength is to unity as the electromotive force is to the resistance.

To keep this ratio true it is evident that if we multiply I by anything, we must multiply E by the same, or divide R by it. This is an algebraic discussion. Translated into words, it states that the current strength in a circuit can be increased by increasing the electromotive force in the same ratio or decreasing the resistance in inverse ratio.

The equation is subject to algebraic transformations. If we preserve the unitary divisor, these changes can be pictured in the mind by imagining a diagonal cross to be placed between the two members of the equation; any quantity can be transferred along the line pointing to it from one end to the other if the figure 1 is put in its place. Written out it should appear thus:

$$\frac{I}{1} \times \frac{E}{R}$$

R can join I as a multiplier; I can join R; or E can join 1. Any quantity deserting its place leaves unity behind it. This gives two good working forms of the equation, in the first of which the unitary divisor is omitted:

$$R\,I = E \text{ and } \frac{I}{E} = \frac{1}{R}$$

Algebra is the shorthand of arithmetic, and some knowledge of it should be acquired.

Direct and Inverse Proportion.—The expressions

$$1 : 2 :: 5 : 10, \quad 4 : 2 :: 1/3 : 1/6$$

are complete proportions, and state that 1 is to 2 as 5 is to 10, and that 4 is to 2 as 1/3 is to 1/6. The first one states that 1 and 2 are directly proportional to 5 and 10; the next one states that 4 and 2 are inversely proportional to 3 and 6.

An inverse proportion is written out exactly on the lines of a plain direct proportion, except that the reciprocals of one pair of quantities are used. A reciprocal is a fraction inverted, or for integral numbers may be described as unity divided by the

number. Either pair may be expressed fractionally in an inverse proportion. The two following are identical proportions:

$$\frac{1}{A} : \frac{1}{B} :: 71 : 15, \quad A : B :: \frac{1}{71} : \frac{1}{15}$$

Percentage.—If a percentage is expressed, it must be written as a whole number; thus, ten per cent is written 10%; fifteen per cent is written 15%. As these figures denote ten or fifteen for every hundred of the original quantity, they can only give a result as multipliers after division by 100. The division by 100 is effected by putting in the decimal point; to divide a whole number by 100, the decimal point is placed so as to leave two digits to its right. It is immaterial whether the percentage figure, the original amount, or the result be thus divided. Thus, 10 per cent of 175 may be calculated in three ways

1.75	175	175
10	0.10	10
17.50	17.50	17.50

The last is the simplest way; the second is the best way. An improvement in scientific nomenclature would be to abandon the term per cent, and to use decimals in its place, as ten one-hundredths or fifteen one-hundredths. Ten per cent would then be written, not thus: 10%; but thus: 0.1.

This system lends itself to the reverse operation. Suppose it is asked what per cent of 175 26.25 is. We perform the division: $26.25 \div 175 = 0.15$. Then multiplying 0.15 by 100 we get 15, which is our percentage, fifteen per cent, or 15%. It would be simpler to ask what decimal of 175 is 26.25. On dividing we would at once obtain the result without any multiplication by 100 or shifting of the decimal place. It would be 0.15, or fifteen one-hundredths.

Fractions.—In expressing in speech or writing fractions having for denominator hundreds, thousands, or millions, some number, such as "one," should always be put before the denominator. Endless confusion results from neglect of this simple rule. Thus

"five hundred thousandths" might be interpreted to mean either

$$\frac{500}{1000} \text{ or } \frac{5}{100{,}000}$$

The first should be expressed as five hundred one-thousandths, the second as five one-hundred-thousandths. Other numbers than one may apply. Thus we might have

$$\frac{500}{15000} \text{ or } \frac{515}{1000}$$

which read five hundred fifteen-thousandths or five hundred and fifteen one-thousandths respectively.

In naming fractions never use the word "over," as a over b for $\frac{a}{b}$. If it is a numerical fraction, say one-half or three-fourths, or better yet, when applicable, "one divided by two," "three divided by four." For literal fractions, such as $\frac{a}{b}$ always say a divided by b, and so for others.

In addition to avoiding the inelegancy and incoherency of the "over" nomenclature, this fixes on the mind something that cannot be too firmly grasped; namely, that a fraction is a sign of division. $\frac{3}{4} = 3 \div 4$. It may even be put as a process of long division, thus:

```
4)3.00(0.75
   28
   ——
    20
    20
```

Compound Fractions.—Compound fractions sometimes present a certain amount of difficulty. This is overcome completely if two things are kept in mind: First, that to divide one fraction by another, the divisor must be inverted and then the new nominator multiplied by the nominator of the dividend, and the new denominator by the denominator of the dividend. Secondly, that any whole number can be expressed as a fraction by drawing a line under it and placing 1 beneath it.

Suppose ¾ is to be divided by ⅝. The latter is the divisor. It is inverted and the multiplication performed as described:

$$\frac{3}{4} \div \frac{5}{8} = \frac{3}{4} \times \frac{8}{5} = \frac{24}{20}$$

Suppose ¾ is to be divided by 5. We write 5 as a fraction, namely, $\frac{5}{1}$, invert it, and multiply.

$$\frac{3}{4} \div \frac{5}{1} = \frac{3}{4} \times \frac{1}{5} = \frac{3}{20}$$

The above operation can be expressed by a compound fraction. ¾ divided by 5 may be written as a fraction, thus:

$$\frac{\;\frac{3}{4}\;}{5}$$

which can be expressed by a division sign, thus:

$$\tfrac{3}{4} \div 5 = 3/20$$

The thick line in the compound fraction indicates that 5 is the divisor of the fraction.

Let the same three numbers in the same order be written thus:

$$\frac{3}{\;\frac{4}{5}\;}$$

This indicates that 3 is to be divided by 4/5. We may express it thus:

$$3 \div \frac{4}{5} = \frac{3}{1} \times \frac{5}{4} = \frac{15}{4}$$

The position of the thick line determines whether the result is $\frac{3}{20}$ or $\frac{15}{4}$.

The best plan in writing such fractions is to use an oblique line for the fractional component; thus, for the two examples given:

$$\frac{3/4}{5} \text{ and } \frac{3}{4/5}$$

It is to be regretted that this system is not more rigorously followed.

The suggestion that such cases be dealt with by treating whole numbers as fractions with unity as denominator is applicable in many other cases. Many people advance in mathematics, and remain subject to a certain amount of confusion in just such points. An analogous and very common case is that of one who employs logarithms, but never uses the characteristic, relying on common sense for the decimal point, which is a very poor plan to follow.

Inverted Addition and Subtraction.—When two numbers have to be added, the best way is to begin at the left hand. The same applies to subtraction. The process is termed inverted addition and subtraction. The following rules for these processes are abbreviated from Newcomb:

Before adding two figures, notice if the sum of the preceding figures is greater than 9. If so, add 1 to the sum. If the sum of the preceding figures is exactly 9, then see if the next but one preceding figures exceed 9. If so, then 1 is to be added. If less than 9, add nothing. If equal to 9, try one more place to the right.

Suppose we have to add the following:

$$\begin{array}{cccccccc} 1 & 6 & 7 & 8 & 6 & 4 & 3 & 4 \\ 5 & 3 & 2 & 1 & 3 & 5 & 6 & 6 \\ \hline 7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}$$

Proceed as follows: Starting at the left, $5 + 1 = 6$. The next figures to the right are equal to 9. Hence we must see if the next pair are greater than 9. They also are equal to 9. So we go on to the right until we find $4 + 6 = 10$. Therefore we must add 1 to our first sum of the left-hand figures and put under them 7. The next two figures $6 + 3 = 9$ have to have 1 added, and 0 is written in all the way along until we get to $4 + 6 = 10$, under which 0 is written, giving us as sum the figures shown. It is very seldom that so complicated an example would occur.

Subtraction is performed on the same lines. An example follows:

$$\begin{array}{r} 3\ 7\ 8\ 1\ 3\ 2\ 4\ 1 \\ 1\ 5\ 2\ 9\ 4\ 1\ 5\ 6 \\ \hline 2\ 2\ 5\ 1\ 9\ 0\ 8\ 5 \end{array}$$

Proceed as follows: 3 — 1 = 2; 7 — 5 = 2; 8 — 2 = 6; but we see that 9 is greater than 1, the next couple to the right, so 6 has to be reduced by 1, making 5 the next figure. 11 — 9 would be 2, but we see that 4 is greater than 3 in the next couple, and therefore write 1 in the next place, 13 — 4 gives 9, because 1 is less than 2 in the next couple. 2 — 1 would give 1, except that 5 is greater than 4 in the next couple. Therefore 0 is written. 14 — 5 gives 8, because 6 is less than 1 in the right-hand couple.

Multiplication and Division.—In many cases a multiplier or a divisor can be factored or divided into two single digits, which multiplied together will produce the number. Thus, if we have as multiplier 63, it can be expressed as 9 × 7. To multiply a number by 63, we may first multiply by 9, and then multiply the product by 7, or the reverse.

Suppose we have a lot of wires of 749 circular mils each; and suppose that 49 of them are to be put in parallel. What is the sum of their areas? We may say 749 × 49 = 36,701; or as 49 = 7 × 7, we may say 749 × 7 = 5243; and 5243 × 7 = 36,701.

The answer by either method is 36,701 circular mils.

Suppose that 27 feet of wire is found to have a resistance of 22.3 ohms. What is the resistance of a foot of this wire? It may be calculated by long division: 22.3 ÷ 27 = 0.8259; or as 27 = 3 × 9, we may say 22.3 ÷ 3 × 7.4333, and 7.4333 ÷ 9 = 0.8259.

The answer by either method is 0.8259 ohm resistance per foot.

The latter example could have been done by dividing in succession three times by the number 3, thus: 22.3 ÷ 3 = 7.4333; 7.433 ÷ 3 = 2.4777; 2.4777 ÷ 3 = 0.8259.

Certain products may be memorized. Thus 256 is the product of 16 by 16 or of 8 by 32; 125 is the product of 5 by 25; 625 is

the product of 25 by 25. One who is much engaged in arithmetical computations acquires a stock of these products.

To multiply by 5 annex one cipher to the number and divide by 2. Thus, $78 \times 5 = 780 \div 2 = 390$.

To multiply by 25 annex two ciphers and divide by 4. Thus, $69 \times 25 = 6900 \div 4 = 1725$.

To multiply by 15 annex a cipher to the quantity and add thereto one-halt of the new quantity. Thus, $181 \times 15 = 1810 + 905 = 2715$.

To multiply by 125 annex two ciphers to the quantity and add thereto one-quarter of the new quantity. Thus $181 \times 125 = 18{,}100 + 4525 = 22{,}625$.

Anyone can extend the general process here indicated indefinitely.

To multiply the squares of several numbers, multiply the original numbers and square the product. Thus, $81 \times 64 \times 49 = (9 \times 8 \times 7)^2 = 504^2 = 254{,}016$.

If the two last digits of a number are divisible by 4, the whole number is divisible by 4. Thus 1924 is divisible by 4, because 24 is; but 1914 is not divisible by 4, because 14 is not.

If a multiplier lies between 1 and 200, the multiplication by it can be effected by percentage addition, or subtraction. Thus to multiply by 101 add one per cent to the number and multiply by 100. The multiplication is done by moving the decimal point two figures to the right, or what is the same, by carrying out the number two places in that direction by adding two ciphers. Suppose 2029×101 is required. One per cent of 2029 is 20.29. Adding this to the original number, we have $2029 + 20.29 = 2049.29$. Moving the decimal point two figures to the right, we have 204,929.

The rule is to take the difference between the multiplier and 100 as a percentage. Multiply by 100 and add or subtract as the multiplier is larger or smaller than 100.

Thus, to multiply 2029 by 75, first multiply by 100. This gives 202,900. The difference between 75 and 100 is 25. As 75 is less than 100, 25 per cent of 202,900 is to be subtracted from it. $202{,}900 - 50{,}725 = 152{,}175$.

To divide accurately by the percentage method, the divisor

must be taken as the basis of the percentage. The number is first divided by 100 by moving the decimal point two figures to the left. Then to or from the result is added or subtracted the percentage of the divisor which the difference between it and 100 is. Thus, for the divisor 75, the difference between it and 100 is 33 1/3 per cent of 75.

To divide approximately by such numbers, the regular way is generally the best, except for numbers near 100. Then percentages can be added or subtracted for an approximate result. Thus, to divide by 95, add 5 per cent; to divide by 105, subtract 5 per cent, in both cases dividing by 100. This is only approximate. To divide by 105 we should by the percentage method subtract 4.762 per cent and not 5 per cent, and multiply by 100. To divide by 95 we should add 5.263 per cent and not 5 per cent, and multiply by 100.

The percentage method is more easily applied to multiplication than to division.

Two numbers of two places each, and which have the same figure in the unit places or in the ten places can be multiplied together thus: Multiply unit by unit. If the figures in the ten places are alike, add the unit figures together and multiply by the quantity in the tens of one number. Then multiply the tens. Add the three for the answer. Thus, to multiply 47 by 49:

$$\begin{array}{rr} & 9 \times 7 = 63 \\ 9 + 7 = 16; & 16 \times 40 = 640 \\ & 40 \times 40 = 1600 \\ \hline & 2303 \end{array}$$

If the figures in the unit places are the same, multiply the units as before; add the quantities in the tens of both numbers, and multiply by the units in one number. Multiply the tens, and add the three products. Thus, to multiply 74 by 94:

$$\begin{array}{rr} & 4 \times 4 = 16 \\ 90 + 70 = 160; & 160 \times 4 = 640 \\ & 90 \times 70 = 6300 \\ \hline & 6956 \end{array}$$

Two numbers ending in 5 can be multiplied by a similar process. Multiply together the figures to the left of the 5 in one number by the corresponding figures in the other number. Add to the product one-half the sum of the numbers just multiplied together and annex 25.

Thus to multiply 65 by 75:

$$\begin{array}{lr} 7 + 6 = 13;\ \frac{13}{2} = & 6.5 \\ 7 \times 6 = & 42 \\ \hline & 48.5 \\ & 25 \\ \hline & 4875 \end{array}$$

The decimal place is used above in order to indicate where the 25 is to be annexed; it goes next to the decimal place if such is required. If the sum of the tens is an even number, no decimal place appears.

Squares of Numbers.—If we know the square of any number, we can obtain the square of the number next above it by adding to the known square the sum of the numbers.

Thus, $12^2 = 144$. This is a familiar number. To obtain from it the square of 13 we simply add $12 + 13 = 25$ to it, giving 169, which is the square of 13. Suppose we know that $16^2 = 256$; then by adding $16 + 17$ to it we get $256 + 16 + 17 = 289 = 17^2$.

The converse is true. We may by subtracting the original number and the one below it get the square of one next lower than the first one. Thus, $16^2 = 256$; $256 - (16 + 15) = 225 = 15^2$.

There is a certain value in this for the calculation of the squares of odd numbers. The squares of even numbers can be calculated by an easy method if they can be factored or divided into two factors, one less than 12 and the other less than 3. When thus divided, square both factors and multiply the squares together. The reason for restricting the process to numbers with small factors is to have the small square less than 16. Anyone can multiply by 9 mentally; but it is not so easy to multiply by 16.

Suppose 18 is to be squared. This can be factored as 6×3. Squaring both and multiplying, we have $36 \times 9 = 324$. Or it may be factored as 9×2. Proceeding as before, $81 \times 4 = 324$; $18^2 = 324$.

This is only applicable to even numbers. The passage to the square of an odd number is done by the method just described. Suppose 19 is to be squared. By the above method we find that $18^2 = 324$; adding to 324 the sum $18 + 19 = 37$, we have $361 = 19^2$.

The largest number to which it is worth while to apply these combined processes is 36, which factors into 12×3. Squaring, we have $144 \times 9 = 1296 = 36^2$.

A very easy way of squaring numbers less than 100 is the following: Subtract from the number to be squared the difference between it and the next multiple of 10 just above it. Multiply the reduced number by the multiple of 10 and add the square of the difference between the original number and the multiple of 10.

Suppose 37 is to be squared. 40 is the next multiple of 10, and 3 is the difference. $37 - 3 = 34$; $34 \times 40 = 1360$; $3^2 = 9$; and $1360 + 9 = 1369$.

The multiple of 10 next below may be used if nearer the original number. The difference is to be added to the original number, the multiplication is effected, and the square of the difference is added.

Suppose 63 is to be squared. 60 is the nearest multiple of 10, and 3 is the difference. $63 + 3 = 66$; $66 \times 60 = 3960$; $3^2 = 9$; and $3960 + 9 = 3969$.

The proof is demonstrated by algebra. Let a be the number to be squared, and b be the decimal next above it; let $b - a = m$. Then $b = a + m$, and the reduced number $= a - m$. By the rule $(a + m) \times (a - m) = a^2 - b^2$, or the product is equal to a^2 less b^2, and to get a^2, b^2 must be added to the product. But by the regular formula the product of the sum and the difference of two numbers is equal to the difference of their squares.

A number ending in 5 can be squared or multiplied by itself thus: Multiply the figures next to the 5 on its left by a number one higher, and annex 25 to the product. Thus to square 25 we proceed as follows: 2 is the figure next to 5 on its left;

3 is the number one higher than 2. $2 \times 3 = 6$. Annexing (not adding) 25, we have as the answer 625. To square 165 we multiply 16 by 17, giving 272, and annexing 25 we have 27,225 as the answer.

Cancelation.—Cancelation is a process which is rather neglected, yet which may be very useful.

Suppose we have to divide 1894 by 707. Instead of doing it by long division, we may apply cancelation, thus:

$$\begin{array}{r|l} \cancel{707} & \cancel{1894} \\ 101 & 270.571 \end{array}$$

We have divided both numbers by 7, and canceled the original ones. Instead of dividing by 101, we simply diminish 270.571 by 1 per cent, which is done by subtracting from it 1/100 of itself, thus: $270.571 - 2.705 = 267.865$, for an approximate result.

It is obvious that cancelation is not always of much use. In the above example it is only of value as it enables us to use the percentage method. Often numbers are so intractable that cancelation is quite inapplicable. The essential is that the divisor shall be divisible by some number without giving a remainder. Cancelation always gives a simplification in such cases, but it is often hardly worth while to use it.

The limitations of the percentage method must be kept in mind. Often as above the only thing which makes cancelation of value is the applicability of the percentage method.

Power of Ten or Exponential Notation.—This adjunct to calculations has become almost indispensable in working with units based on the C. G. S. system. It consists in using some power of ten as a multiple, which may be called the factor. The number multiplied may be called the characteristic. The following are the general principles.

The power of 10 is shown by an exponent which indicates the number of ciphers in the multiplier. Thus 10^2 indicates 100; 10^3 indicates 1,000 and so on.

The exponent, if positive, denotes an integral number, as shown in the preceding paragraph. The exponent, if negative, denotes the reciprocal of the indicated power of 10. Thus 10^{-2} indicates $\frac{1}{100}$; 10^{-3} indicates $\frac{1}{1000}$ and so on.

The compound numbers based on these are reduced by multiplication or division to simple expressions. Thus: $3.14 \times 10^7 = 3.14 \times 10{,}000{,}000 = 31{,}400{,}000$. $3.14 \times 10^{-7} = \frac{3.14}{10000000}$ or $\frac{314}{1000000000}$. Regard must be paid to the decimal point as is done here.

To add two or more expressions in this notation if the exponents of the factors are alike in all respects, add the characteristics and preserve the same factor. Thus:

$$(51 \times 10^6) + (54 \times 10^6) = 105 \times 10^6.$$

$$(9.1 \times 10^{-9}) + (8.7 \times 10^{-9}) = 17.8 \times 10^{-9}.$$

To subtract one such expression from another, subtract the characteristics and preserve the same factor. Thus:

$$(54 \times 10^6) - (51 \times 10^6) = 3 \times 10^6.$$

If the factors have different exponents of the same sign the factor or factors of larger exponent must be reduced to the smaller exponent, by factoring. The characteristic of the expression thus treated is multiplied by the odd factor. This gives a new expression whose characteristic is added to the other, and the factor of smaller exponent is preserved for both.

Thus:

$(5 \times 10^7) + (5 \times 10^9) = (5 \times 10^7) + (5 \times 100 \times 10^7) = 505 \times 10^7$.

The same applies to subtraction. Thus:

$(5 \times 10^9) - (5 \times 10^7) = (5 \times 100 \times 10^7) - (5 \times 10^7) = 495 \times 10^7$.

If the factors differ in sign, it is generally best to leave the addition or subtraction to be simply expressed. However, by following the above rule, it can be done. Thus:

Add 5×10^{-2} and 5×10^3.

$5 \times 10^3 = 5 \times 10^5 \times 10^{-2}$; $(5 \times 10^5 \times 10^{-2}) + (5 \times 10^{-2}) = 500005 \times 10^{-2}$. This may be reduced to a fraction $\frac{500005}{100} = 5000.05$.

To multiply add the exponents of the factors for a new factor, and multiply the characteristics for a new characteristic. The

exponents must be added algebraically: that is, if of different signs the numerically smaller one is subtracted from the other one, and the latter's sign is given the new exponent.

Thus:

$$(25 \times 10^6) \times (9 \times 10^8) = 225 \times 10^{14}.$$
$$(29 \times 10^{-8}) \times (11 \times 10^7) = 319 \times 10^{-1}.$$
$$(9 \times 10^8) \times (98 \times 10^2) = 882 \times 10^{10}.$$

To divide, subtract algebraically the exponent of the divisor from that of the dividend for the exponent of the new factor, and divide the characteristics one by the other for the new characteristic. Algebraic subtraction is effected by changing the sign of the subtrahend, subtracting the numerically smaller number from the larger, and giving the result the sign of the larger number. (Thus to subtract 7 from 5 proceed thus: $5 - 7 = -2$.)

Thus:

$$(25 \times 10^6) \div (5 \times 10^8) = 5 \times 10^{-2}$$
$$(28 \times 10^{-8}) \div (5 \times 10^3) = 5.6 \times 10^{-11}$$

Logarithms.—The use of logarithms can be learned in a few hours. All manuals of algebra give the theory, and the application with examples is generally given in manuals of trigonometry. The table of logarithms is generally given in the latter manuals, but not in algebras.

Logarithms should be taken in the right aspect, as an aid to multiplication and division and extraction of the square root, and as an almost indispensable assistance in extracting higher roots. They assist immensely in arithmetic, and thorough familiarity with them should be acquired.

The only point which presents the least difficulty is the characteristic—for some obscure reason this is regarded as a sort of obstacle by the beginner. There is even a tendency to omit it altogether in calculations. This tendency is a very bad one. The characteristic should be written out always, because sooner or later cases will arise when its absence will occasion confusion and error.

The logarithms of constants are often included in tables of logarithms, and are frequently very useful.

A number of tables of logarithms are published in book form. In purchasing one, see that the type and printing are clear.

Angular Measurement.—A unit circle is a circle whose radius is equal to 1, or whose diameter is equal to 2.

Angles are measured by the fractional part of the arc of a circle which they include in their sweep. The arc of an entire circle is divided into 360 parts called degrees, and indicated by a little circle at the top of and following the figures, thus: 45°, 90°, reading "45 degrees," "90 degrees." It will be observed that the angle has no linear measurement, feet or inches for example. The degrees assigned to it express its proportional measurement, the whole circle being taken as equal to 360°.

Thus 45° are $\frac{45}{360}$ or ⅛ of an entire circle, 27° are $\frac{27}{360}$ or $\frac{3}{40}$ of an entire circle.

The length of the circumference of a circle is expressed in terms of its diameter, thus: $\pi\ d$, d standing for diameter, and π for 3.14159+.

In alternating current formulas, some quantities are used which are what are known as functions of angles. Such are the sine, cosine and tangent. These three are the principal ones employed in alternating current formulas, and are all that will be described here.

The cut, Fig. 1, shows a circle. It has two lines drawn across it through the center. Such lines are called diameters. One-half of a diameter measured from the center to the circumference is called the radius. The angles begin at the right-hand end of the horizontal diameter, and are counted toward the top of the circle, and so all around it against the movement of the hands of a clock. The upper end of the vertical diameter marks the end of an angle of 90°; the left-hand end of the horizontal diameter, an angle of 180°; the lower end of the vertical diameter, an angle of 270°; and coming back to the starting point, the right-hand end of the horizontal diameter, an angle of 360°, or one of 0°, according to how it is taken.

Radian System of Angular Measurement.—A radian is the angle measured by the arc of a circle equal in length to the radius. The circumference of a circle of radius 1, which is the unit circle, is 2 π, which is equal to 6.2832—. A circle with a radius of 10 inches measures about 62.8 inches around. The circumfer-

ence of a circle contains 2 π radians; a radian is equal to one circumference of a unit circle divided by 2 π. Radians are shown in Fig. 2; they are the six equal angles which nearly fill the circumference.

As the circumference of a circle is equal to 360 degrees, a radian is equal to $360° \div 2\pi$, or $\frac{360°}{6.2832—} = 57.3°$ approximately.

When 2 π appears in a formula, it is generally in the radian system.

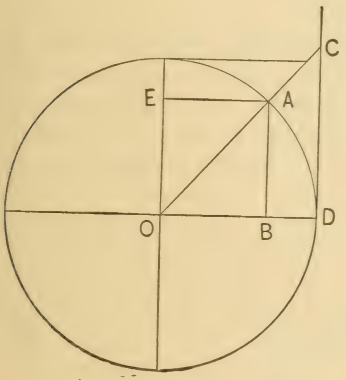


FIG. 1.—SINE, COSINE AND TANGENT.

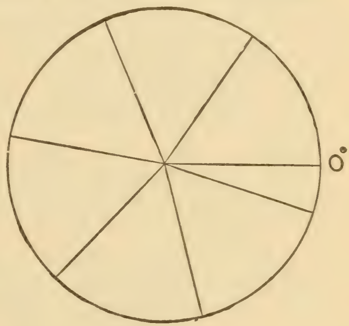


FIG. 2.—RADIANS.

Trigonometric Functions.—Fig. 1 is a circle. It is divided into quarters by two diameters, one horizontal and one vertical. The quarters are designated by numbers, and referred to their arcs, which are quadrants. The upper right-hand quadrant is the first quadrant; the upper left-hand quadrant is the second quadrant; and the lower left-hand quadrant is the third quadrant, and the other is the fourth quadrant.

A radius O A prolonged outward determines an angle in the first quadrant. The vertical line from the outer end of the radius to the horizontal diameter is the sine of the angle. This sine is marked A B; the angle is included between the lines O D and O A.

The sine of an angle is always a vertical line, and is always measured up or down, as the case may be.

The horizontal line from the outer end of the radius O A to the vertical diameter is the cosine of the angle. The line E A is the cosine of the angle.

The tangent of an angle is the vertical line from an extremity of the diameter to the prolongation of the radius marking the angle. For the angle shown, the tangent is the line indicated by the letters D C.

The numerical value of the sine divided by that of the cosine gives the numerical value of the tangent.

Numerical Values of Circular Functions are expressed in terms of the radius, which is taken as 1 except in logarithmic tables, when it is taken as 10^{10}. The value when logarithms are dropped is taken again as 1. The value can be applied to a circle of any radius by multiplying it by the radius of the circle in question.

Greek Letters.— π. This is the Greek letter *p*. It is best pronounced "*pi.*" If the Continental pronunciation "*pee*" is used, there is danger of confusing it with the English letter *p*. Suppose that a quantity denoted by *p* is to be multiplied by π ; confusion would at once ensue if π was called "*pee*" and not "*pi.*" It indicates the factor by which the diameter of a circle must be multiplied to give the circumference. For approximate calculations its value may be taken as 3 1/7, or what is the same thing, 22/7. If decimals are to be used, 3.1416 or 3.14159 may be used, the latter being accurate enough for almost any purpose. The very usual custom of multiplying the diameter by 3 to get the circumference is so very inaccurate that it should never be used.

Take a circle of 37 inches diameter. Multiplied by 3 it gives 111 inches circumference. Multiplied by 3 1/7 it gives 116 2/7 or 116.286 inches circumference. Multiplied by 3.1416 it gives 116.239 inches circumference. Multiplied by 3.14159 it gives 116.2388 inches circumference.

Reduced to sevenths, the last two products read between 1/7 and 2/7 for their fractional part. The error in 116 2/7 is only 0.0469 inch, or about 1/20 of an inch. It is evidently unnecessary for every-day work to use the decimal expressions.

The exact value of π has never been calculated. It has been deduced to over a hundred places of decimals.

θ. This is the Greek "*th*," or *theta*, a double letter as we would call it in English; it is really an aspirated "*t*." It is used a great deal in alternating current calculations, to indicate the angle of lag in alternating current work.

φ. This is the Greek "*ph*," *or phi*, an aspirated *p;* it is used to indicate the angle through which an alternating current wave has advanced from the 0° position. When vector diagrams are used, the measurement begins from the right-hand end of the horizontal diameter.

ω. This is the Greek *o* (long). It is spelled *omega* and pronounced as spelled. It is used to indicate the frequency of an alternating current in radians per second. Let f equal the frequency per second of the alternations of a current; then $\omega = 2\pi f$. A single cycle takes 2π or 6.2832 radians for its completion. If the numerical value of ω in any given case is divided by 6.2832, the quotient will be the number of cycles per second. The product of ω by t, or $\omega\ t$, is equivalent to φ in formulas relating to alternating current.

Useful Constants.—There are certain constants and figures of frequent use which should be memorized. The value of π is one of these. It is approximately 3 1/7, 3/22, or 3.14159.

The radius of a circle squared is equal to one-fourth of the square of the diameter. One-fourth of π is 0.7854. This is a good figure to remember. The area of a circle is equal to the square of its radius multiplied by π (3.14159), or to the square of its diameter multiplied by $\pi/4$ (0.7854). Thus a circle of one foot diameter is 0.7854 square foot area; one of two feet diameter is of one foot radius and of 3.14159 square feet area.

The factor 0.7854 shows that a circle is approximately 8/10 the area of the square inclosing it. This gives a quick method of approximately finding the volumes of round cisterns and tanks. Suppose a round tank is 12 feet in diameter and 15 feet deep. The area of the inclosing square is $12 \times 12 = 144$ square feet. $144 \times 8/10 = 115.2$ the approximate area of the round cistern, and $115.2 \times 15 = 1728$ cubic feet. This is the approximate volume, which can be made quite close to the truth by the per-

centage method. It is evident on inspection that 0.8 exceeds 0.7854 by a little less than 2%. 1728 less 2% is 1728 — 34 = 1694. The correct answer is a little over 1696.

Many other practical factors and quantities may be noted.

A speed of one mile an hour is equal to 1.45+ foot or 1 foot 5½+ inches per second.

A railway train going one car length per second goes at about 40 miles an hour.

One hundred yards in 10 seconds is about 20 miles an hour.

The number of 30 foot rails passed over in 20 seconds is the approximate speed in miles per hour.

The pull on the draw bar of a car on a level is about 20 pounds per ton per mile an hour. Thus at two miles an hour it is 40 pounds per ton, and so on.

A cubic inch of water makes nearly a cubic foot of steam at atmospheric pressure, half this volume at 15 pounds pressure, one-third at 30 pounds pressure, and so on.

Water is 816 times heavier than air.

A cubic inch of iron weighs nearly one-quarter of a pound; a cubic inch of copper, 0.32 pound; of lead, 0.41 pound.

A cubic foot of water weighs about 62½ pounds.

To reduce kilometers to miles, multiply by 0.6 and add one-thirtieth.

Sixty-two miles an hour is 100 kilometers an hour.

1 kilowatt is equal to a little over 1 1/3 horse-power (1.3404).

1 B.T.U. (British thermal unit) is equal to 772 foot-pounds.

1 cubic foot of air weighs 537 grains.

1 cubic foot of hydrogen weighs 37 grains.

1 liter of hydrogen (the crith) weighs 0.08961 gramme.

Torque.—Torque is force exercised in the rotation of a wheel or similar object, or the force which a rotating wheel or similar object exerts. Thus, in the case of an electric motor its twisting force, or the force with which its shaft is rotated, is its torque. The armature of an active dynamo resists the force which the belt exercises on the belt wheel, and energy or horse-power has to be used to keep it going. This resistance is torque. The strain produced by the belt is driving torque; the resistance offered by the belt-wheel keyed on the armature shaft is the

resisting torque, strictly speaking. Of these two terms, the one most used is driving torque only. In a motor the case is reversed. The armature is drawn around and kept in rotation by the field magnets, and the armature exercises torque, and by means of its torque, and because of it, can drive machinery. In the generator, the belt exercises torque; in the motor, the armature exercises it.

If we know the torque and the speed of the machine, we have the actual horse-power.

Torque is usually expressed in this country in pounds pull on a one-foot radius, which is that of a 2 foot pulley or belt-wheel.

The horse-power exerted by a motor whose speed and torque are known may be calculated by the following formula. In it T indicates torque, H. P. horse-power, r radius of torque, S revolutions per minute of the motor shaft.

$$\text{H. P.} = \frac{\text{T} \times r \times 6.28 \times \text{S}}{33{,}000}$$

Suppose the torque exerted by a 4-foot belt-wheel driven by a motor was 10 pounds, and that the motor made 2,000 revolutions per minute. Substituting these figures, the formula becomes:

$$\text{H. P.} = \frac{10 \times 2 \times 6.28 \times 2000}{33{,}000} = \frac{251{,}200}{33{,}000} = 7.612$$

actual horse-power.

If a machine is rated at a definite horse-power and speed, the torque is calculated by the next formula, which is a transposition of the other.

$$\text{T} = \frac{\text{H. P.} \times 33{,}000}{r \times 6.28 \times \text{S}}$$

Suppose a 7¾ horse-power machine has a speed of 2,000 revolutions at full load. To determine the torque on a pulley of 4 feet diameter, which gives $r = 2$, we substitute as below:

$$\text{T} = \frac{7\frac{3}{4} \times 33{,}000}{2 \times 6.28 \times 2000} = \frac{255{,}750}{25.120} = 10.18$$ pounds torque at 2 feet radius.

In these formulas the factor 6.28 is 2π, or the factor by which the radius of a circle must be multiplied to give the circumference.

It is practically accurate to consider the torque of an electric machine identical when run either as dynamo or motor if the speed and current are the same. In many cases it is easy to run a dynamo as a motor. The Prony brake in some of its many forms can be applied, and the torque determined with the simplest possible appliances. The torque developed by the dynamo when run as a motor is taken as that which would be absorbed by it when run as a dynamo.

Actual horse-power, or that exerted by a machine, is often

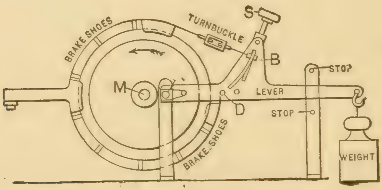


FIG. 3.—PRONY BRAKE.

called brake horse-power, because it is determined by a Prony brake.

The Prony Brake is an apparatus for determining the horse-power of a machine, such as a steam engine, or electric motor, or dynamo. A Prony brake is shown in Fig. 3. A belt pulley is turned by the machine under trial; the pulley is keyed to the shaft M. A strap brake passes around it, armed with wooden shoes. One end of the strap is fastened at D, the other at B. The latter fastening is adjustable by the screw and hand-wheel S. The arrow indicates the direction of rotation of the wheel. The hand-wheel S is turned until the weight is just held in equipoise, with the lever between the two stops. A spring balance is often used instead of the weight. The shaft under the conditions outlined above rotates with power enough to sustain the weight on the lever or that indicated by the spring balance. Calling the half diameter or radius of the pulley r, and the dis-

tance from the center of the shaft to the point of application of the weight L, we have for the turning stress or force, which is torque, of the shaft M:

$$\text{Torque} = \frac{\text{Pull} \times r}{\text{L}}$$

From the torque thus determined and the number of revolutions the horse-power is obtained by the formula below:

$$\text{Horse-power} = \text{Torque} \times \frac{6.28\ \text{S}}{33{,}000}$$

in which S is the number of revolutions per minute made by the machine. The torque is the force component, the rotation of the shaft is the space component, and the two give energy, and the energy rate is power.

The Dynamometer is an appliance which indicates the power a machine at work in exerting, when the speed of the machine is known, indicating directly the force. This force may be exercised directly, as when a team of horses is pulling a wagon or when a locomotive engine is pulling a train of cars. A spring balance used as draw bar or coupling link is a dynamometer for such cases. Its reading in pounds multiplied by the speed of the horses or engine in feet per minute, and divided by 33,000, gives the horse-power.

If the dynamometer gives the torque or pull of a belt, then the radius of the pulley must be known, and the revolutions per minute. Formulas will then give the horse-power.

In the illustration, Fig. 4, a transmission dynamometer is shown. It transmits the power of a machine, whence it derives its title. *c* is a shaft connected by a universal joint *c′* to the machinery to be driven. The pulley C with inside teeth is keyed to this shaft. It is turned by the pulley B, and B is turned by the pulley A, to whose shaft *a a* with universal joint the working machine is connected. Noting the directions of rotation indicated by the arrows, it will be seen that B driven by A has its axle forced downward. It is acted on with more or less force, according to the power exercised by the machine. The lever D, on which B is mounted, has a limited range of motion about its ful-

crum at D. This motion is counteracted by the weight P, acting through the lever T on the knife edge *e* of the lever D. The torque can be taken at any time without interfering with the running of the machine, and without absorbing any of its power.

Luminiferous Ether.—This is a theoretical thing whose existence has never been proved. It is assumed to be the cause of the dissemination of light and of the phenomena of electricity. It is best thought of as something like a gas but so much more tenuous that it cannot be detected in any way. It passes through many substances, especially through non-conductors of electricity such as glass. Conductors of electricity are almost impenetrable by it. On this distinction between transparent and opaque bodies, the first not conducting electricity and the others conducting it, is found a basis for the theory that light and electricity are closely related. Clerk Maxwell's celebrated electromagnetic theory of light leads to the same conclusion, and a confirmation for it may be found in the opacity of conductors such as metals and graphitic carbon and the transparency of non-conductors such as glass, amber and carbon in the modification known as diamond. This is a general statement, and open to qualifications which it is unnecessary to introduce here.

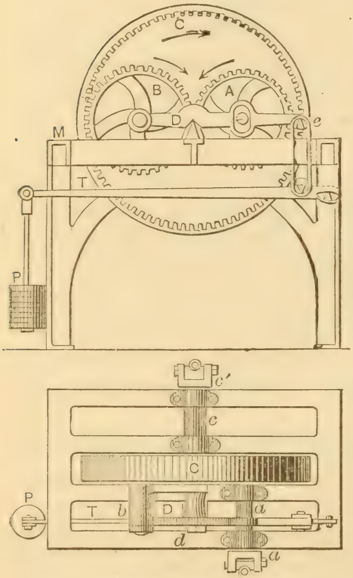


FIG. 4.—THE DYNAMOMETER.

CHAPTER II.

ELECTRIC QUANTITY AND CURRENT.

Electric Quantity.—While electricity is about the most indefinable word used in science, we have as a starting point to assume that it is of such a nature as to be susceptible of possessing quantity. We have to use the conception of definite and definable quantities of electricity without being able to say what we mean by electricity itself. The conception of an electric current is that of the transfer of quantities of electricity along a wire or conductor, just as in a current of water gallons are transferred through a pipe. An electric current heating the filaments of incandescent lamps, producing the electric arc between carbon terminals, exciting electric magnets and driving powerful motors, is familiar enough. But the idea of quantities, stored up in receptacles, is less so.

A quantity of electricity may be stored upon the surface of any insulated body. Coincident with its storage is the storage of another equal quantity of opposite polarity somewhere else. A quantity of electricity cannot be stored or charged upon a surface unless an equal and opposite charge is stored elsewhere.

It is something like chemical decomposition. It is impossible to take a quantity of hydrogen from water without producing a corresponding quantity of oxygen, equal thereto in saturating power.

Storage of Electric Quantity.—The surface of bodies seems to be the only part concerned in the storage of electricity. The coexistence of two charges and the impossibility of a single charge existing by itself, caused the early investigators to found the two-fluid theory of electricity. Current phenomena are treated more simply by assuming the existence of a single electric fluid. The assumption is therefore made, although rather out of harmony with the phenomena of electric charges.

One of these phenomena is that two oppositely-charged surfaces attract each other, and that their charges tend to combine, forming a current while doing so. But the single-fluid *versus* double-fluid controversy is an academic question; there is certainly no fluid in electricity; and we can speak of a current as of water, or of positive and negative charges as of oxygen and hydrogen in the water molecule *ad libitum.*

Condensers.—The typical receptacle for electricity is termed a condenser. It comprises two surfaces adapted to receive and to conduct electricity, insulated from each other. To enable the surfaces to conduct electricity to every part of their area, and to give it up when wanted, they are made of metal. To save space the metal is thin. To separate and keep them insulated from each other, and to modify, owing to a most curious property, their storage capacity, an insulating material is placed between

FIG. 5.—THE CONDENSER IN SECTION.

them. A sheet of paper as insulator, with a sheet of tinfoil on each side of it, is a condenser.

Paper is not procurable of unlimited area, and the same is true of tinfoil. It would also be very inconvenient to have condensers as big as table-cloths. Acccordingly, to increase the area of the tinfoil it is piled up like the leaves of a book, with paper between the leaves. Every leaf of tinfoil is kept in electric connection with the leaf once removed from it. This brings the tinfoil into two sets, the pieces of each set being in connection with all pieces of its own set and insulated from the other set. The cut, Fig. 5, shows the arrangement in a diagram of its cross section.

The dark lines a, a_1, and a_2 represent one set of sheets of tin-

foil, all connected together. The dark lines b, b_1, and b_2 represent the other set, also connected together. The shaded part intervening represents the dielectric, which may be paper, mica, or glass. In some standard condensers it is simply air, plates of metal being used instead of tinfoil. A and B are the conductors, by which it may be charged and discharged. They are twofold, so that one pair can be used for the charge and one for the discharge. One set of sheets receives a positive charge (+) when the other receives a negative one (—).

Fig. 6 shows the way a condenser is built up. It is inclosed in a box with binding posts for the two sets of leaves. Various modifications of connections are applied in practice.

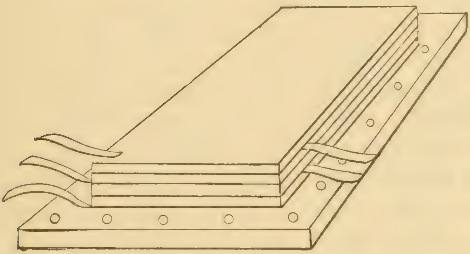


FIG. 6.—THE CONDENSER.

Charging.—If electricity of one kind is poured into or over the surface of one set of leaves of tinfoil, the other electricity must be given some means of accumulating on the other leaves. Therefore, simultaneously with the pouring in of one kind, means must be provided for accumulating another kind. One must be poured over one set of tinfoil, and the other over the other.

If a charge is to be given by a galvanic battery, for instance, its opposite terminals, A and B must be connected one to one set, a, a^1, a^2, the other to the other set, b, b^1, b^2, of tinfoil sheets. In an exceedingly short space of time each set receives its charge. The tinfoil being a conductor, conducts the current everywhere. To discharge the condenser, the oppositely-charged sets of tinfoil are brought into electric contact, the current passes

for an infinitesimal space of time in one direction, and then in diminished intensity in the other, and so beats back and forth like the swinging of a pendulum until the charge is gone, and the opposite electricities have combined. The quantity of electricity which constituted the charge has disappeared.

Meaning of Quantity of Electricity.—It would seem that there must be the same quantity of electricity in the condenser after as before the discharge. But a "quantity" of electricity is determinable by and recognized by its effects. The discharged condenser is perfectly neutral and inert, therefore there is no quantity of electricity in it. Keeping clear of the question of double or single-fluid theory, we may conclude that electric quantity is quite different from hydraulic quantity, which is gallons, liters, or other measure of a fluid. The same is to be said of electric current. It is far different from a current of water. But it is convenient to treat the electric phases of quantity and current as being analogous to quantity and current of water or steam. It is in the actions of water and steam that convenient analogies to electric action are found.

Earthing a Condenser.—Another way of charging a condenser is to connect one set of leaves to the earth, or "earthing" it. The earth is arbitrarily taken as of zero potential. If one kind of electric excitation is imparted to the set of leaves not connected to the earth, the electricity of the same kind is expelled into the earth out of the other set. There is another way of picturing the action, treating the earth as an inexhaustible reservoir of negative electricity, ready to receive negative electricity from one side of a condenser, leaving it positively charged, or to pour in negative electricity, leaving it negatively charged.

Capacity of Condensers.—The quantities of electricity which can be stored in condensers are exceedingly small. An incandescent lamp may use up a coulomb of electricity every second. It would take an enormous condenser to supply it for even a single minute. Such condensers accordingly in practical use are largely employed in the class of electrical work requiring slight currents, such as telegraphy and telephony. The accumulation and instant discharging of quantity following each other in rapid succession play an exceedingly important *rôle* in much work in

modern electricity, where alternating currents accumulate quantity, discharge it, and accumulate it again twenty-five to sixty times in a second. This opens another field for the use of condensers. The effect of the action is treated of by engineers under the term "capacity."

A condenser charged with a quantity of electricity greater or less, as the case may be, can be taken away from its connections and carried about like a pail of water. Electricity could be poured out of it into another condenser, and it could thus establish a current. The distant end of an Atlantic cable might be connected directly to the earth. Then if one set of leaves of a charged condenser were also connected to the earth, a very brief current could be sent through the cable by connecting the other set of leaves to its ungrounded near end.

Single Surface Condenser.—A quantity of electricity can be accumulated and held upon any insulated conductor. A piece of tinfoil on the middle of a sheet of glass could be charged with a quantity of electricity. This would at first sight seem precisely the same as pouring water into a receptacle. But the dual element has not disappeared. The charged bit of tinfoil produces an opposite charge on objects around it, on the surface of the experimenter's skin, on the walls of the room, and elsewhere, there being theoretically no limit to the area affected. The little bit of tinfoil only operates as a container of electrical quantity in conjunction with surrounding objects. It represents one set of leaves of the condenser, the surface of surrounding objects represents the other set of leaves.

Unit of Quantity.—A quantity of electricity stored in a condenser is termed a charge. Poured through a conductor, it produces a current. It is thought of as a measurable thing, and its unit is called the coulomb. A current of one coulomb per second is called a current of one ampere. One coulomb at a potential of one volt constitutes a unit of energy called the volt-coulomb or joule (pronounced "*jowl*"). A joule is equal to nearly one-thousandth of a British thermal unit; 1047 joules have energy enough to heat one pound of water one degree F.; 746 joules would exercise one horse-power for one second.

This is not a direct way of estimating the coulomb, because it

is used as a factor of a compound unit, but energy units are so familiar that this method of conceiving of the value of a coulomb is of use. A coulomb of electricity as such is often considered as producing direct results. The most that can be said is that results follow the application of electric energy which vary in direct proportion with the coulombs. A coulomb without association with electromotive force can do nothing, and properly speaking cannot be directly measured by its effects, but can be indirectly measured by effects which vary in direct proportion with electric quantity.

At Niagara Falls tons of aluminium are produced by electric decomposition of chemical compounds (haloid salts) of aluminium. The quantity of metal produced is due to coulombs of electricity passed through the fused mixture containing the aluminium salt or salts. An enormous number of coulombs of electricity are used annually in the production of aluminium.

In electro-plating works silver is deposited in greater or less thickness upon tableware and other articles. The quantity of silver deposited depends upon the quantity of electricity used in doing it. One coulomb of electricity deposits 1.134 milligrammes of metallic silver. It will separate from water about 172 cubic centimeters of a mixture of hydrogen and oxygen gases. This gives a sort of relation between electric quantity and concrete measures and weights, which makes electric quantity more realizable than it would be without such aids to the imagination.

A thunder cloud as one surface, with the earth's surface and the surfaces of all objects thereon as the other surface, can store up quantities of electricity just as a condenser can. A square mile of thunder cloud, at such tension of electromotive force as to be ready to discharge a lightning stroke, need only have a quantity of electricity of seventy coulombs in its charge. Its quantity of electricity would only deposit 80 milligrammes of silver from a plating solution.

Coulombs of electricity forced by electromotive force through conductors of properly adjusted resistance produce quantities of heat with accompanying light, of incandescent and arc type. Forced through motors, quantities of mechanical energy are produced, measured by foot-pounds or other unit. In these opera-

tions of electric light and power, the energy produced or absorbed is always expressible by a compound unit, such as the foot-pound. These operations are due also to a twofold action of electricity; they are due to potential drop and to quantity combined. In the compound units, such as foot-pounds, by which the action of combined potential and quantity is measured, we discern always a potential unit, the foot for instance, and a quantity unit, such as the pound. To them corresponds the compound unit of electrical energy spoken of above, the volt-coulomb or joule, 1.356 of which are equal to one foot-pound of mechanical energy.

Electric quantity can be measured by things amenable to the simple processes of weighing and measuring. There is danger, on account of this direct proportion existing between electric quantity and the effects of electric energy, that the agency of electromotive force will be overlooked.

The coulombs passed through a decomposable solution are directly proportional to the quantity of products of decomposition. But for this decomposition a fixed quantity of electromotive force is required. Therefore a constant value of electromotive force for each case accompanies each decomposition, so the natural tendency is to leave it out of consideration, although the coulomb would be impotent without accompanying voltage or electromotive force.

But when heat energy comes into question, the simple ratio disappears, and it is found that heat energy is proportional to volt-coulombs or joules; not to coulombs, but to coulombs raised to the second power. This is the reason why, in referring electric quantity to quantities of physical energy, the joule was used instead of the coulomb on a preceding page.

The Storage of Quantity of Electricity involves a factor that applies to the storage of any physical thing, namely, capacity.

Capacity is the relative power of storing electricity of a surface or combination of surfaces.

Electricity charged upon a surface tends to escape from it and to join that upon the oppositely-charged surface. This tendency establishes a potential difference or electromotive force between the two surfaces.

Capacity is defined quantitatively by means of this potential difference. A condenser which will hold one coulomb of electricity at a potential of one volt has a capacity of one farad.

It is somewhat as if we should say that a vessel which would hold 5270 grains of air at a pressure of ten atmospheres would have 1728 cubic inches capacity. The weight of the air represents the quantity or the coulombs, the ten atmospheres represent the voltage or the volts, and 1728 cubic inches represent the capacity or the farads. All this is simply an analogy. If the pressure of the air were doubled, the capacity of the vessel would be unchanged, but it would hold twice the quantity of air that it held at the lower pressure. It is manifest that the capacity of a vessel could not be expressed in grains or other weight of air unless the pressure of the air were specified. A unit of capacity different from the unit of quantity is needed.

It is exactly so with electric capacity. The potential or electromotive force of its charge must be expressed to define the capacity of a receptacle of electric quantity. This is why different units are used for capacity and quantity. A measure of a capacity of one gallon holds a quantity of water defined as one gallon, and holds this amount under all circumstances and conditions. But an electric measure of fixed capacity, such as a particular condenser, can hold any quantity of electricity until it breaks down and discharges through its dielectrics, puncturing them and destroying its materials of construction, if they are susceptible of injury.

Dielectrics.—The substance separating two oppositely-charged conducting surfaces is called the dielectric. It may be any substance which will not conduct the electric current, as otherwise the surfaces would discharge into each other. The nature of the dielectric affects the operation of the condenser, and the effect depends on specific inductive capacity or inductivity.

Specific Inductive Capacity or Inductivity.—The nature of the insulating substance or dielectric which separates oppositely-charged surfaces has an effect upon the voltage or potential difference due to a charge of a given quantity. Air and gases are the poorest dielectrics. Sulphur is 3.2 times better than air. Assume two sheets of metal separated by air and brought by a

certain charge or quantity of electricity to a potential difference of 3.2 volts. If a layer of sulphur of equal thickness separated them, their potential difference would be only 1 volt. The relative quality of dielectrics in this regard is called Specific Inductive Capacity, or Inductivity.

The inductivity of some dielectrics is given here. Air, it will be recollected, is 1, and a vacuum about the same.

Glass	3.0 to 10.00	Shellac	2.95 to 3.60
Vulcanite	2.50	Turpentine	2.15 to 2.43
Paraffin	1.68 to 2.30	Petroleum	2.04 to 2.42
Beeswax	1.86	Sulphur	3.20
Mica	4.00 to 8.00		

The application of these figures is to be seen in the formula for calculating the capacity of a condenser. This formula for microfarads is

$$K = 885 \times 10^{-10} \times \frac{k\ a}{x}$$

In this formula a is the area in square centimeters of all the leaves of dielectric between the conducting plates; x is the thickness of the dielectric, and k is the inductivity.

Examples of Capacity.—The capacity of the earth is only 0.007 farad, or 7,000 microfarads, and that of the sun is 0.076 farad, or 76,000 microfarads.

Polarized electrodes immersed in an acid solution have immense capacity. Two square inches of platinum electrode immersed in dilute sulphuric acid, and polarized a little over 1/50 volt, have a capacity of 175 microfarads. This is the capacity of 80,000,000 square inches of tinfoil or other metal surface separated by ⅛ inch of air. If the platinum is more highly polarized, its capacity increases. The polarization is brought about by using them as electrodes for the decomposition of water. Hydrogen adheres to and is occluded by one plate, and oxygen by the other. This establishes a difference of potential between them. The description of Grove's gas battery given elsewhere may be referred to in this connection.

Microfarad.—The farad is too large a unit of capacity for

ordinary use, so a microfarad, or one one-millionth of a farad, is the standard unit.

Current and Rate Units.—The working electrician is so accustomed to deal with electricity in action, that his mind always turns in that direction. The mechanical engineer deals in many units of energy, such as the erg, foot-pound, and the like; but the electrical engineer instinctively refers to electricity in its effects. A charged condenser does not look a bit different from an uncharged one, though one contains potential electric energy.

But an active conductor is surrounded with thermic and other phenomena in the way of force and energy, which make the bringing out of the recognition of its activity by the eye an easy matter. Current intensity is the thing most easily recognized and whose effects are most often witnessed. It is the production of current that is the end and aim of nine-tenths or more of engineering practice. For such reasons as the above the ampere, a unit of rate of quantity transfer, is far more used than the coulomb, a unit of quantity alone.

The above shows the origin of a clearly discernible habit of thought among electricians. They do most of their work with rate units of quantity and of energy. Such units are for rate of quantity, which is current, the ampere; for rate of energy, which is power, the watt.

Conductors and Non-Conductors.—The old-time division of substances into conductors and non-conductors of electricity had so much truth in it, that it is preserved to the present time. There is a group of substances that conduct the electric current well; there is another group that conduct it so badly that they are termed insulators and non-conductors, although every one of them has some conducting power. It is fair to say that between the two extremes thus broadly stated is a field containing comparatively few substances. The majority of substances can be put into one or the other category.

Ether Waves Produced by Electricity.—If an electric disturbance is produced, the luminiferous ether is disturbed, waves are produced in it, and the disturbance is propagated through space. For waves to be produced in a medium, it must possess restitutive power. Mechanical waves can be produced in water,

because its particles move practically without friction between each other. Any disturbance rectifies itself by the particles working back to their original position and disseminating waves. The absence of intermolecular friction makes restitutive power possible. The force of gravity is the force called on to effect the restitutive action, which restores eventually to their places the particles disturbed by the action which caused the waves. Water is elastic, and without any visible disturbance can propagate waves of a totally distinct type, whose production is due entirely to its elasticity and not to its absence of friction or to its weight. Such waves are sound waves. Water conducts sound because its elasticity gives it the restitutive power required for the sound wave. The elasticity of the air makes it also a conductor of sound, and gives it restitutive power for the sound wave. We can hear the hum of an insect high over us in the air, and hardly realize that his minute vocal organs start a series of waves which disturb a mass of air of many tons in weight. The diaphragm of a telephone receiver, acted on by a field due to the irregular current induced by the voice of a distant speaker, is forced into vibrations which reproduce the voice. The elasticity of the iron plate is the restitutive power making possible the starting of sound waves from it as a new center.

Action of a Conductor.—If we use the idea of a current in speaking and thinking of electric action, we may picture to ourselves the following representation of the action of a conductor. An electric disturbance is produced in ether, and ether waves are set in motion. But just because the ether is restitutive, it resists the transfer of anything resembling quantity. Any attempt of quantity to escape from a center through the ether is futile. The elasticity of the ether throws it back on itself.

But if a tube were opened through the ether, quantities of electricity could be poured through it, and the choking effect of a restitutive medium being removed, transfer of quantity could take place. This gives us the clue to a useful presentation of the conduction of electric quantity—of the electric current flowing through a conductor.

An electric conductor such as a wire of copper, iron, or aluminium, can be pictured as constituting an ether-free cylinder, a tube free from the restitutive ether, and quantities, such as coulombs, of electricity can flow through it.

Crude as the above may seem, especially in view of the ion theory, it presents a useful analogy for current transmission by a conductor.

Time Required to Produce a Current.—Suppose we had a long tube or pipe through which we began to pump a fluid such as water. It would take some time for the water to reach the end. If a current of electricity is started in a conductor which has some capacity, it takes a measurable time for the current to be appreciable at the further end, and a considerable time before it reaches full strength at the further end. Once it has attained this strength, it can be maintained indefinitely.

If the water pipe were inclined a little upward, the water would take a measurable time to reach the end, and would reach it at first as a thin layer, and would require some time to be emitted in full strength. The gradual increase of flow at the distant end would be still better shown by a pipe which was level, better yet, inclined downward.

Let the pipe be inclined downward, and the water would flow under the influence of gravity. It would first trickle in drops or in a relatively small stream from the end, and would only gradually acquire the strength of the entering current. This strength once acquired would be maintained.

Production of Current.—The water acts like the electric current in the latter case, as its entire mass is acted on by gravity. Every particle is pushed along individually; it is not merely an end push. A similar action is predicated for an electric conductor. The current is pictured as urged through it by action all along the conductor from the surrounding ether. An electric current is not due to a simple end thrust.

Current Amperes and Coulombs.—An electric current then is the flow through a conductor of a quantity of electricity caused by electromotive force. As a current is a thing of some duration, frequently of very long periods, we have to define its volume as it passes by us, and say it is of so many coulombs per

second, for instance. We can save the enunciation of two words by omitting "coulombs per second," and saying "amperes" instead. An ampere of current is one coulomb per second. If an ampere flows for one minute, it is the transfer of 60 coulombs; if 60 amperes flow for one second, it is the transfer of 60 coulombs also.

The electric current is caused by electromotive force, which is measured by units called volts; it passes through conductors whose relative qualities are generally expressed by stating their relative resistances in units called ohms. We can have a circuit including an electromotive force of ten or any number of volts, and also any number of ohms. Such a circuit may be spoken of from the standpoint of electromotive force or resistance as a ten-volt circuit or a ten-ohm circuit, but neither epithet can be applied to a current. The expression a ten-volt current or a hundred-volt current, once so frequently used, is just as bad a misnomer as such expressions as a ten-ohm or a hundred-ohm current would be.

Current Strength or Intensity.—The intensity of a current is measured and defined by the quantity of electricity it transfers in a unit of time. It is the rate of transfer of electric quantity. Its intensity or strength has to be measured in quantity-time units, such as coulomb-seconds, which are amperes. The latter word is universally used, as a ten-ampere or twenty-ampere current. The true conception of an ampere has presented such difficulty to many students that it is open to question whether it would not be preferable to use the double unit coulomb-second in its place. It is, of course, too late to introduce any such change now.

Analogy for the Ampere.—A good analogy for the ampere is the miner's inch. This is a measure of rate of flow of water. It is in universal use in the western mining districts. It is the quantity of water which will pass through an aperture one inch square in a board two inches thick under a head of six inches. The cut, Fig. 7, illustrates the conditions. In one second a miner's inch delivers 0.1937 gallon of water, just as an ampere in one second delivers one coulomb of electricity.

The head of water may be taken as representing electromotive

force, and the obstruction offered by the limited size of the hole as representing resistance.

Speed of a Current.—It will now be evident how absurd is a question often asked: How long will it take for electricity to go through a wire of any given length, such as the Atlantic cable? The first trace of current may go through with the velocity of light, but it will take a measurable time for the current to attain sufficient strength to affect the telegraphic instruments in use on the line. It is not even a question of the

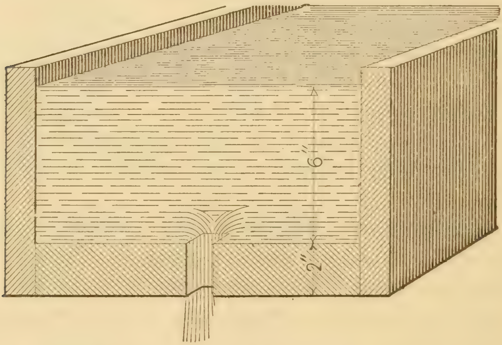


FIG. 7.—THE MINER'S INCH ANALOGY OF THE AMPERE.

velocity of propagation of an electric disturbance—it is a question of charging a conductor of tangible and perhaps very great capacity.

Arrival Curve.—The current's slow growth at the end of a long conductor is indicated by a wave-like curve. In sea cables this arrival curve, as it is called, is rendered more abrupt by the use of condensers. To illustrate how slowly a current may reach its full strength, the Atlantic cable worked directly may be cited. Starting with it uncharged and connecting it as part of a circuit, 108 seconds would be required before the current would attain 9/10 of its full value. In 1/5 second it would attain 1/100 of its full value. Theoretically, an infinite time would be required for attaining the full strength of the original current.

This feature of slow growth of current is greatly diminished in extent by the use of condensers, so that the above example is not a practical one.

Direction of a Current. Memoria Technica.—The idea of a moving of or transferring of electric quantity through a conductor implies a direction of the current thus formed. This direction has to be established on conventional grounds. To remember it, we may refer to the galvanic battery for a convenient *memoria technica*. In the battery the zinc plate is the active one. The other plate may be pictured to the mind as merely gathering electricity and delivering it to the conductor. The current in the outer portion of a galvanic battery's closed circuit flows from the copper, platinum, or carbon plate to the zinc plate. The letters of the alphabet give the clue, as *z*, standing for zinc, is the last letter of the alphabet, and the zinc is the last to receive the current.

Field of Force and Lines of Force Due to Current.—The ether surrounding a conductor seems to play a part in urging a current through it. In electricity everything goes by reciprocals, and a current affects the ether which surrounds it. It is thrown into a state of stress, circular lines of force which build up a sort of cylinder around the conductor being formed.

Every impulse of electric current that goes through a telegraph wire produces circular lines of force around the wire, somewhat as if it was thickly strung with rings. This occurs for the whole miles of length of the wire. Once produced, the lines of force persist as long as the current lasts.

Electromotive Force.—This may be defined as electric pressure which under certain conditions causes electric current. It is comparable to the pressure of steam in a boiler, which will force a current of steam through an opening, just as electromotive force will force a current of electricity through a conductor. It is not energy, but appears as a factor of energy in the joule or volt-coulomb, and as a factor of power in the watt or volt-ampere. The practical unit of electromotive force is the volt, and the term voltage is often used as a synonym of electromotive force, as is also the expression potential difference, drop of potential, or difference of potential. As will be seen later,

there is a distinction to be noted. Electromotive force is often written in abbreviated form as E. M. F. or e. m. f., and is often spoken of by these three letters.

Production of Electromotive Force.—It is produced in various ways. If chemical changes are allowed to take place in obedience to chemical affinity, electric energy is set free, and the e. m. f. constituent of it is produced. Mechanical energy can by the dynamo- or magneto-generator be converted into electrical energy, and electromotive force appears. The economical production of electric energy, with the inevitable impressment or production of electromotive force, is one great object of the study of the electric engineer.

Dynamic and Static Electricity.—Electricity in the manifestation called a current is treated as dynamic electricity. The current can never exist without the coexistence of electromotive force. Electromotive force can exist without a current. The latter condition is called static electricity.

Electromotive Force and Energy.—It is fair to say that electromotive force is always associated with some form of electric energy. An instance of static electricity is a stick of sealing wax rubbed upon the coat sleeve. This has a very high electromotive force impressed upon it, and if connected to the earth will produce a current. The electromotive force while in the static condition was a constituent of potential electric energy. This statement is a broad one, but expresses the general condition, and like other broad statements may be open to some modification.

One of the most familiar sources of electromotive force is a galvanic battery. On closed circuit this will maintain a current due to electromotive force produced by chemical change. The existence in a battery of chemical combinations or substances whose affinities call for chemical change, shows the presence therein of potential energy. As long as the elements of the battery tend to satisfy their affinities by chemical change, so long will they represent potential energy and will maintain electromotive force.

When the battery becomes exhausted, the chemical affinities no longer strive to be satisfied as before, and the electromotive

force disappears simultaneously with the potential energy of the battery.

If the battery is on closed circuit, the electromotive force produces a current, and active or kinetic electric energy appears. If the battery is on open circuit, electromotive force is still there as a component of inactive potential electro-chemical energy.

Suppose a wire ring cut in one place were moved across the field of an electro-magnet. If this were done in a certain way, electromotive force would be impressed upon the ring. If while so moving its ends were tested, they would cause the reading of a voltmeter to show the presence of voltage on the circuit. The energy element of this combination is purely potential as long as the ring is discontinuous. A voltmeter may, as said above, be used to close the gap, when energy will at once appear, because a current passes through the winding of the voltmeter. This is another example of the association of electromotive force with potential energy.

In the mechanical world the analogous condition obtains. It is hard to conceive of force except in coexistence with potential or kinetic energy. A mass of matter, a stone or weight, solicited by gravity represents force, and also potential energy, because if released it will fall and develop kinetic energy. But place it at the center of the earth, and it will no longer tend to fall; it will lose its power to produce kinetic energy, and it will cease to possess weight. Force will disappear because gravity no longer acts upon the body, and simultaneously with the disappearance of force, potential energy will disappear, because the body in its new position can no longer produce kinetic energy. The force centered in the body disappears simultaneously with the potential energy due to that force and to its position with reference to the earth. The comparison excludes cosmic forces; it refers only to terrestrial gravity.

Conservation of Electricity.—The cause of electromotive force is conveniently referred to the assumption that there are two kinds of electricity, positive and negative. Or if it is desired to avoid any revival of the old double fluid versus single fluid controversy, a change in nomenclature will effect it; we

may term the two kinds of electric disturbance positive and negative excitation or charging. A positively-charged body attracts a negatively-charged one, and in this attraction is to be sought the cause of current, which cause is electromotive force.

Whenever one object is positively charged, an opposite or positive charge is imparted to some other object or objects, which theoretically may be even the celestial bodies. This opposite charge is equal in amount, so that a sort of analogy to the doctrine of the conservation of energy, is found in electricity. The algebraic sum of the positive and negative electricities or electrical charges in the universe is equal to zero.

This doctrine has been called the Law of the Conservation of Electricity.

Electromotive Force and the Static Charge.—The conception of the necessary existence of an opposite charge for every charge of electricity, and of the fact that any object may act in this *rôle*, is very important. It tells against the conception of electromotive force as a simple pressure or push, but suggests that it must operate in some way on both extremities of a circuit in opposite senses, or over the whole length of a conductor. Taking an analogy from everyday mechanics, it suggests a bar moved in the direction of its length by a pull at one end and a push at the other end of the bar, given together at the same time. The value of this analogy is to prevent the idea that electromotive force acts only on the end of a conductor pushing electric current through it. Although the action is still the object of theorizing, it is certain that it is not so simple as that.

Electromotive Force in Thunder Clouds.—When a cloud becomes charged with electricity, the earth becomes charged oppositely. The two tend to combine, and the tendency may become so intense under enormously great electromotive force that the opposite electricities combine in a series of currents of inconceivably short duration, and which surge back and forth, also for an infinitesimal space of time, and constitute the lightning stroke.

There the electromotive force may mount into millions of volts, and project a large quantity of electricity through the enormous resistance of air, so as to produce destructive effects.

It is no trivial force that splits trees as we see them when lightning has struck them, especially when we realize that but a small portion of the stroke may have been exerted on the tree, the majority expending itself on reaching the tree through the air. Irregular tubes of melted sand are sometimes found in the earth. These have been formed by the heat of the electric discharge of lightning. A very tangible quantity of heat is needed to effect the melting. When we realize that it is done in an infinitesimal space of time, it is evident that the rate of heat energy and of electric energy (watts) causing it is very high.

The action of electromotive force in the disruptive discharge of electricity, such as that seen in the Leyden jar discharge or in the lightning stroke, is far different from its action in producing an ordinary current such as passes through a wire of an electric circuit. The violent discharge of the jar or of the lightning beats back and forth somewhat like a rebounding ball, but it is the same electromotive force that is operative in producing the minute currents that affect the telephone. The lightning discharge, with its oscillations, is comparable to the alternating currents of telephony somewhat as are sound waves in air to light waves in the ether from the standpoint of frequency. The two are cited as illustrations of the extremes of electromotive force. That of the lightning is almost immeasurable on account of its magnitude, that of the telephonic circuits is the same on account of its minuteness. A lightning stroke a mile in length is calculated to absorb an electromotive force of 5,000,000,000 of volts, the telephone current, calculated at about 1/100 of a microampere, requiring an electromotive force of about 1/1,000,000 of a volt for its development. An electromotive force of one volt is a little less than that of a Daniell cell in good order.

Electromotive Force the Cause of Current.—The electric current is caused to flow through a conductor by electromotive force. As all conductors possess some resistance, and as a constant current once started moves through each part of the conductor with equal intensity, we should anticipate that electromotive force would be expended in driving the current through each part of the conductor. This is what actually occurs.

Drop of Potential.—We start at the origin with a definite electromotive force, and it grows less and less as we progress along the line. Ohm's law (page 18) expressed as $R = \frac{E}{I}$ tells us that the electromotive force varies with the resistance. Hence if from beginning to end of a conductor a drop of 10 volts is observed, then, for every portion of the conductor of 1/10 its total resistance, a drop of 1 volt exists.

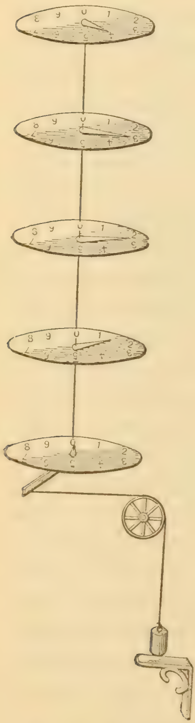


FIG. 8.—TORSION WIRE ANALOGY.

Analogies of Drop of Potential.—A simple analogy may be taken from a wire, Fig. 8, hanging vertically from a bracket and subjected to twisting at its lower end. To show the action pointers are to be fastened to it at intermediate points of its length, projecting at right angles from the wire. As the bottom is twisted, each pointer turns through an arc. The pointer nearest the bottom turns through the longest arc, that nearest the top through the shortest arc, and the intermediate ones through arcs proportional in length to their distance from the end. If the degrees through which the pointers move are treated as volts, the drop in volts along a wire conducting a current is illustrated, the twist representing the current.

As the degrees through which the pointers move grow less and less as remoter from the twisted end, so in a conductor the voltage drops. The current is the same throughout it, and in the twisted wire every part of its length is subjected to an identical twisting strain.

Another excellent analogy is shown in Fig. 9. A horizontal pipe conducts water. It has vertical pipes connected to it along its top. The height of the column of water in each of these indicates the pressure at that point. It is evident that it will be less

and less as the outer end of the pipe is reached. The difference of height of any two neighboring water columns indicates the hydraulic drop, an exact analogy of the electromotive force drop.

Electromotive Force and Difference of Potential.—There are two terms which are almost synonymous, yet which have a distinction one from the other—electromotive force and difference of potential. If a difference of potential is maintained between the ends of a conductor or between any two points on it, a current will pass. The intensity of this current can be de-

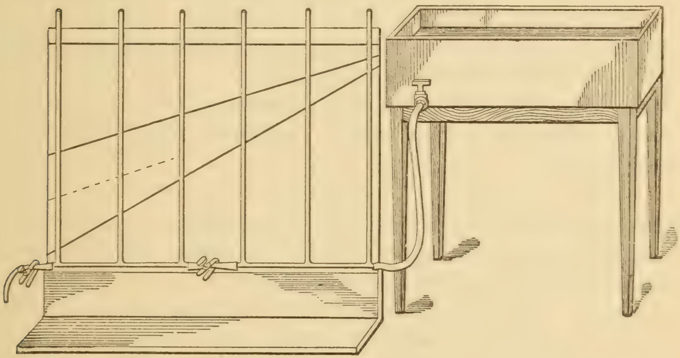


FIG. 9.—HYDRAULIC ANALOGY OF DROP OF POTENTIAL.

termined, the resistance of the circuit can be determined, and the product of the two will give the difference of potential. A suitable instrument of the galvanometer type can be connected to the two points on the circuit, and its reading will give the difference of potential, usually in volts, fractions of or multiples of volts.

This is simple enough. A complete electric circuit may next be considered, consisting of a galvanic battery and an outer circuit connecting its terminals. The resistance of the battery is determined, and also that of the outer circuit. On closing the circuit a current passes, and its intensity is determined. On multiplying the sum of these resistances by the current intensity,

we have as before what appears to be a difference of potential. But if we try to determine the difference of potential by an instrument, such as a voltmeter, we can find no two places to which to connect its terminals, so that it will show the difference of potential we have determined. Its readings are always less.

If a number of electromagnetic lines of force are forced to thread themselves through a closed conducting circuit, such as a ring of wire, a current of electricity will pass through it as long as the lines of force increase or diminish in number. The current will continue to pass as long as any change in their number occurs, and the more rapid the rate of change, the more intense will be the current. Multiplying the resistance by the current as before, we get what we might be disposed to term a difference of potential. But on applying our voltmeter, we can find no two points of the circuit between which more than one-half the difference of potential required to account for the current exists.

The current is due to the electromotive force. If we could connect a voltmeter to two consecutive points of the circuit, and force it to indicate the difference of potential existing between them the long way around, we should find it equal to the electromotive force. But there is no way of doing this. The term difference of potential always indicates the true difference existing between points, which is the minimum one. No hypothetical maximum is allowed for.

Electromotive force includes difference of potential as one of its phases and measures. But many cases occur in which it goes beyond difference of potential, and produces a current perhaps twice as great as could be accounted for by simple potential difference.

Voltage.—This word is almost a synonym of potential difference, except that it includes the idea of its measurement in volts. Applied to an open circuit, it may be identical with the electromotive force existing in that circuit.

CHAPTER III.

THE ELECTRIC CIRCUIT.

The Electric Circuit.—The existence for any time of a current of electricity always implies the existence of what is called a circuit. If two surfaces are oppositely charged, they may discharge into each other, but the discharge will last but a minute fraction of a second and will not be a continuous current. A reservation might be made in the case of a circuit actuated by a battery, but the electrolyte of the battery is always treated as a conductor.

Constitution of a Circuit.—It consists of a conductor whose ends are connected when in action; when they are disconnected temporarily, it is an open or broken circuit. When completed and connected, so that it forms a re-entrant path for the current to flow around, it is called a closed circuit. It is called circuit because its ends are to be joined, making a sort of irregular circle, closed loop, or endless path for the current to go through. A straight piece of conducting material, such as a piece of wire or metallic rod, could be used to carry a momentary current or discharge of electricity, but this would not properly be an electric circuit.

A lightning rod may offer a perfectly straight path for the discharge of a thunder cloud, and powerful electric currents may surge back and forth through it, currents which would make the metal of the rod fairly explode in a white-hot shower of melted metal, were they not of such inconceivably short duration. This is a conductor only, not a circuit.

The galvanic battery, with the conducting wire joining its ends in electrical bonds, gives a continuous, endless path for electrical action. The dynamo with its outer circuit does the

same. The telegraph system or the overhead trolley system, using the earth alone or in part for the return current, is treated as an electric circuit. The earth is taken as representing a conductor, although its function may not be strictly that of a conductor.

Condensers in a Circuit.—A condenser consisting of two conducting surfaces, separated by insulating material, operates as an absolute break in the continuity of a circuit. For a continuous direct current a condenser in a circuit would open it as effectually as an open switch would. Where short pulses of current are to be transmitted, condensers may be introduced in the line. This is often done in submarine cable and telegraph practice. These break the circuit for the passage of a consecutive current, but the dots and dashes of the Morse code are better

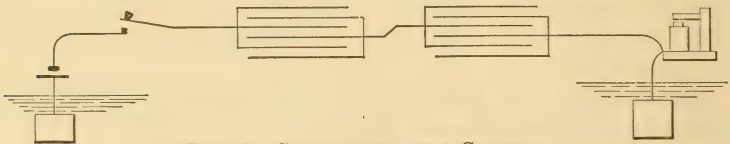


FIG. 10.—CONDENSERS IN A CIRCUIT.

transmitted than by a through metallic connection. Such an arrangement, illustrated diagramatically in Fig. 10, is called a circuit.

Open and Closed Circuits.—If electric conductivity exists all through the length of the circuit without any break, it is called a closed circuit. A prisoner within it would be closed in by it. To get out he would have to find or make an opening. An electric circuit with such an opening is called an open electric circuit. Once the conception of an electric circuit as a closed ring of conductors is formed, the meaning of open and closed circuit is fixed in the mind. To pull a switch away from its contact point, mechanically speaking, opens the switch. This opens any circuit of which it forms a part, and the circuit becomes an open circuit. If the switch is closed, the circuit becomes a closed circuit.

Circuits Without Appliances.—An electric circuit closed and

with a current passing through it may be composed of a simple conductor without any generator or other appliance in it. A piece of wire with its ends joined, constituting a metallic ring or loop, may become an electric circuit. All that is necessary is to move it across a magnetic field of force, so as to cut lines of force under certain conditions, and a current will go through it, and it will become an electric circuit. Conditions for carrying it out are shown in diagram in the cut, Fig. 11.

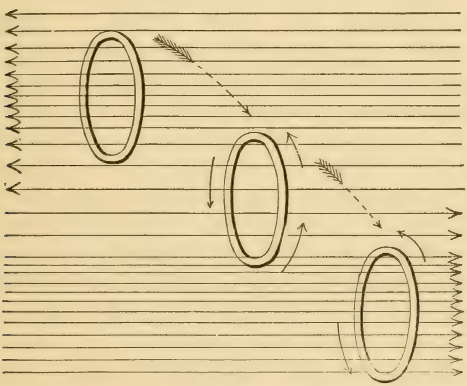


FIG. 11.—RING MOVING IN FIELD OF FORCE UNDER CONDITIONS PRODUCING A CURRENT.

Appliances and Generator in Circuits.—Current is produced in a circuit by electromotive force impressed upon it, and in very many cases a generator or several, such as dynamos or batteries, form part of the circuit. Appliances for utilizing the current, such as lamps and motors, may also be included. In calculating the resistance of the circuit, all must be taken into account.

A galvanic battery may be in circuit with miles of wire in measuring apparatus wound in thousands of convolutions. The battery may include a number of plates of carbon and zinc and half as many separate cups of solution. Or each cup may contain two solutions, kept imperfectly apart by porous diaphragms

or by the difference in specific gravity of the solution. Switches or contact plugs may come in, galvanometers or other apparatus, but the whole, complicated as it may be, constitutes an electric circuit.

Electrolytic Conductors.—If we take the case last cited, we see that the current has two kinds of conductors provided for it, one metallic and the other liquid. Through the liquid portion, except perhaps for a very small fraction of the current, no ordinary conduction of electricity takes place. As the solution is decomposed, electrical excitation accumulates on the plates and is discharged through the outer circuit by true conduction. Within the battery decomposition of the water group takes place, and electrolytic conduction takes place, something quite distinct from true conduction.

An electric circuit may provide true conductors for part of the circuit, and electrolytic conductors for another part.

Actions of a Circuit.—A circuit is the seat of three things—electromotive force, resistance, and current. The current produced in a closed circuit by a given electromotive force is modified by the resistance of the entire circuit, and an identical current exists in all parts of it, whatever the local resistance may be.

Although current is not energy, it cannot pass through a conductor except at the expense of energy, and whenever a current is passing through a conductor, energy is being expended therein. Every part of an active circuit is a seat of energy.

This being the case, it follows that in every part of the circuit electric energy disappears and some other form, usually heat energy, is produced in its place. If we take one point of the circuit as our standard of reference or point of departure, as we go from it we should look for a drop of some kind. The direction of an electric current is so very hazy a conception that we cannot prescribe any direction in which a drop should take place. Abandoning *à priori* deductions, we can go right to the fact.

In any portion of an active circuit we shall find an identical current. Between any two points of an active circuit we shall find a difference in potential by using any of the usual measuring instruments.

When a current is passing through a conductor, the electromotive force causing it is shown in the existence of a difference of potential. The difference of potential between any two parts of an active circuit is called the drop or fall in potential.

We now see how every portion of a circuit carrying a current, which is not energy, is a seat of energy; the drop of potential causing the current is the necessary element. Current multiplied by potential difference is power or rate of energy, and

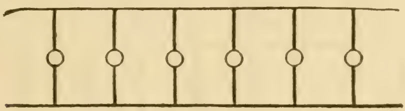


FIG. 12.—MULTIPLE ARC OR PARALLEL CONNECTION.

wherever current exists, a potential difference exists with it. This refers to practical conditions, not to atomic or molecular. Later the conception of the wattless current will be given, and may appear to be somewhat opposed to this statement, but the actual existence of a wattless current is open to discussion.

Parallel and Shunt.—"In parallel with," "in shunt with," "in multiple arc," and similar expressions involving these words indicate a division of the conductor into two or more branches which reunite, so that the current is divided among them. "Branch" applies in the same cases. Fig. 12 shows six appliances in parallel, or in multiple arc.

Series.—A series connection indicates that one appliance follows another, as shown in Fig. 13.

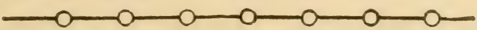


FIG. 13.—SERIES CONNECTION.

Series Multiple.—This indicates a connection in series of such groups of lamps as shown in Fig. 14. Each group has to pass the same current.

Multiple Series.—This connection is shown in Fig. 15. It is analogous to multiple-arc connection, and each set of lamps in

series has approximately the same drop of potential if the two main leads are large enough.

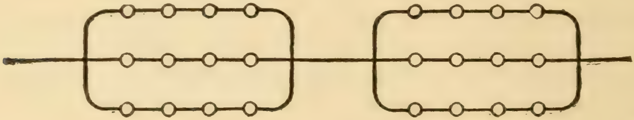


FIG. 14.—SERIES MULTIPLE CONNECTION.

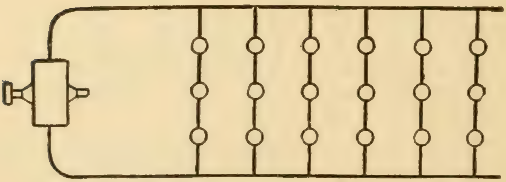


FIG. 15.—MULTIPLE SERIES CONNECTION.

Series and Parallel.—The expression three in series and two in parallel indicates that there are a total of $3 \times 2 = 6$ appliances arranged in two parallel series of three each, as shown in Fig. 16. Two in series and three in parallel indicates that six appliances

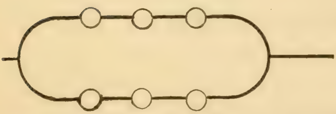


FIG 16.—THREE IN SERIES AND TWO IN PARALLEL.

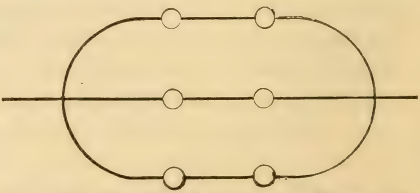


FIG. 17.—TWO IN SERIES AND THREE IN PARALLEL.

are arranged in three parallel series of two cells each, as shown in Fig. 17. This class of expression can be varied indefinitely, as ten in series and five in parallel and the like.

Outer Circuit means the portion of a circuit not included in an appliance. Thus a storage battery circuit might include a line of wire, motors, and lamps. The line wire, motors, and lamps

would be the outer circuit; the full circuit would include them and the battery.

Short Circuit.—If from one terminal of a motor a conductor was carried to the other, it would be a shunt for the motor, and if of low resistance compared to the motor, it would "short-circuit" the motor. A conductor of low resistance in parallel with one of high resistance, or in parallel with an appliance absorbing a large drop in potential, is a short circuit for the other conductor or appliance, and is said to short-circuit it.

Conductibility, Conductance, and Conductivity.—The property of conducting electricity is called conductibility. The conducting power of any conductor is called its conductance. The specific conducting power, which is the relative power compared with a standard, is termed conductivity.

The conductance of a conductor depends on several things. The longer it is, the less will be its conductance; while the thicker or greater in cross section it is, the greater will be its conductance. Anything which lowers the conductivity of a conductor affects also its conductance, and in the same way. The conductivity of a conductor is its relative or its specific conducting power as compared with other conductors. It is expressed on the basis of a valuation of the conductivity of the best conductor as one hundred.

As Ohm's law was originally stated for resistance, the quality of conductance is little used, its reciprocal, which is resistance, being universally used in electrical calculations. It is a pity that this is the case, but units of resistance will always remain in use by the engineer. It has a positive action in the production of light and heat. Without resistance electric lamps and heating effects of the current would be impossible.

Resistance.—Resistance is the reciprocal of conductance. It is expressed by $\frac{1}{\text{conductance}}$ and is a conception inferior in every way to conductance, but has been so woven into the science that it will always be used in preference to conductance. No one thinks of a copper wire as an electric resister; a telegraph line is not laid over miles of country to resist the passage

of electricity. An attempt has been made to create a unit of conductance equal to the reciprocal of the ohm. It was proposed by Sir William Thomson (now Lord Kelvin) to give it the rather barbaric name of *mho.* In the interest of etymology it was fortunate that it was abandoned, as in the interest of science it is unfortunate.

The negative aspect of resistance appears in its definition as the property of an electric conductor by which it opposes the passage of an electric current. Specific resistance is the relative resistance of a material; this should be called resistivity. Resistance is generally used to indicate the resistance of some specific conductor, such as actually in use or liable to be employed in practice.

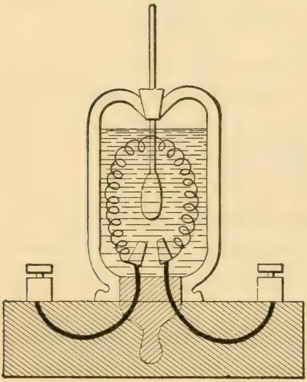


FIG. 18.—ELECTRIC CALORIMETER.

Resistance and Energy.—When a current is passing through an electric circuit, electromotive force has to be expended to drive it through, as the resistance of the circuit opposes the transmission of current, and the current driven by electromotive force through a resistance indicates the expenditure of electric energy. The conductor of definite resistance through which the current is thus forced becomes hot, and this proves that energy has been expended upon it. The energy can only have been obtained through the electric current and electromotive force. Energy results from an electric current passing through a resistance. If different parts of a circuit differ in resistance, the heating effects will be greatest at the points of greatest resistance. Local resistance localizes energy in a circuit.

If a conductor through which a current is passing is immersed in a vessel of cold water, it will heat the water. A thermometer whose bulb is in the water will indicate a rise in the temperature. The apparatus (the electric calorimeter) is shown in the cut, Fig. 18.

The Ohm.—This is the resistance through which an electromotive force of one volt will produce a current of one ampere. There has been much difficulty in determining accurately a standard. Mercury at the temperature of melting ice has been the conductor, and the length of a column one square millimeter in cross section, which would give a resistance of one ohm, was determined. Four ohms came into use, of the following designations and length of mercury column:

True ohm........................	106.24	centimeters.
B. A. ohm........................	104.9	centimeters.
Board of Trade ohm...............	106.3	centimeters.
Legal ohm........................	106.0	centimeters.

The present standard is the International ohm, the resistance of a column of mercury 106.3 centimeters long at the temperature of melting ice, which mercury weighs 14.4521 grammes.

Mercury is of all metals the one most easily purified, and being liquid is unaffected by strain.

Internal and External Resistance.—Internal resistance is the resistance of a generator, whether dynamo or battery. External resistance is the resistance of the portion of a circuit outside of the generator.

Circuit Without Resistance.—Assume that a circuit carries a direct current and has no resistance. It is a purely theoretical conception, and at first sight seems paradoxical. It may be asked what would result were an electromotive force of one volt impressed on the circuit. The first suggestion of a solution would be that an infinite current would result. But an infinite current multiplied by finite electromotive force would give an infinite rate of energy, and this is absurd. The solution lies in a proper appreciation of Ohm's law. In it are linked together three factors—current strength, electromotive force, and resistance. Current strength multiplied by electromotive force is taken as representing rate of energy. Resistance is never absent from an electric circuit, and never will or can be. The unit of rate of electric energy made up of current strength and electromotive force, and called the watt, ceases to be a unit of power unless resistance or its equivalent is opposed to it. A fourth element is omitted from the problem. In the absence of resist-

ance the current would tend to increase indefinitely. As the current increased, it would build up an increasing field of force around the conductor. Energy is required to do this, and by the law of conservation of energy an opposition to the increase of current would result. The formation of a field of force is accompanied by the development of counter electromotive force, which is electromotive force operating in the reverse direction to the original. Energy is required to increase the strength of a current in a circuit under these conditions. The current would go on increasing forever, building up an increasing field of force, and energy would be absorbed on the circuit as long as electromotive force was impressed on the circuit.

Electrolytic Conduction.—When two plates of metal or other conductor are immersed in a solution which does not attack them, and are not in contact with each other, if a sufficient potential difference is established between them, a current may pass. It will pass if the liquid is an electrolyte. An electrolyte is a liquid decomposable by electricity. Even solids are supposed to some extent to be subject to electrolysis. Electrolytic conduction is conduction at the expense of the electrolyte which is decomposed.

Suppose two plates of platinum are immersed in a solution of dilute sulphuric acid. Let the plates be connected to the terminals of an electric circuit, and let a difference of potential be established between them. If the difference of potential is less than a volt, a very minute current will pass. Next let the potential difference be increased. Nothing occurs until a certain potential difference is attained, about 1.48 volt, when suddenly a strong evolution of gas occurs from both electrodes and a current passes, which is many times stronger than the preceding one.

It is unnecessary at this place to discuss the ion theory. The old view of electrolysis is still to be considered the practical one. Electrolysis is the separating of a substance into two constituents differing from each other in chemical relation. An electrolyte must be a compound substance. By the action of the current it is separated into two unlike substances. It must have such a composition that it can be resolved into two parts.

The way the conduction takes place is thus explained: The solution touching one of the electrolytes gives up to it a part of its chemical constituents. The rest combines with the opposite constituent of the next layer of solution, displacing its similar constituent, and this takes place all through the liquid until the other electrode is reached. At its surface necessarily there is set free the opposite constituent of the electrolyte. Such is the old theory, and one which holds its ground with many at the present day.

Thus in the case of the acidified water, hydrogen is liberated at one pole, setting free oxygen. This instantly combines with the hydrogen of the next sheet of molecules, setting free its oxygen. The action is repeated until the other electrode is reached, at which oxygen is liberated. Exactly the quantity of hydrogen required by chemical laws to combine with the oxygen is set free. The two gases are liberated in exact chemical relation with each other.

If chemically-pure water is used, electrolysis will be greatly reduced. It is probable that with pure water there would be none, but water always contains some impurity, and it is impossible to perfectly purify it. We are justified, however, in saying that for electrolysis to take place in water, some salt or soluble substance must be present.

Water containing a dissolved substance is not the only electrolyte. Frequently there are substances which when melted by heat become electrolytes. Chlorides and fluorides of the alkaline and other metals are electrolytes when they are melted and are kept in liquid state by heat. Such electrolytes are used in the production of metallic aluminium by the Hall process. From such electrolytes tons of aluminium are precipitated in the works at Niagara Falls and elsewhere.

Solutions of metallic salts in water form the electrolyte used for electroplating. The metal is deposited on the article to be plated, and an anode, as it is called, of the metal of the bath is often employed, which is dissolved and keeps up the strength of the solution.

CHAPTER IV.

OHM'S LAW.

Three Elements in a Circuit.—There are always three things present or to be taken into account in considering the operation of an electric circuit. They are so bound up with its existence as known to us that we cannot eliminate any of them. The first one is current intensity, which is due to the second one, electromotive force, acting against the third one, resistance. They are indicated in formulas by the respective letters C or I for current intensity, E for electromotive force, and R for resistance.

Ohm's Law, following out what has been said in the last few pages, is to the effect that current intensity is equal to electromotive force divided by resistance. The statement expressed as an algebraical equation becomes:

$$I = \frac{E}{R}$$

If the equation be taken in its broadest sense, the exposition of its effect just given covers it. If it be applied to a specific circuit, which therefore is of fixed resistance, it tells us that current intensity is proportional to electromotive force. If the voltage in any part of a circuit is doubled, the current will flow with double intensity through that portion.

The case may arise where a fixed electromotive force exists and the resistance varies. The equation states that in such a case the current intensity is inversely proportional to the resistance. With a fixed electromotive force, doubling the resistance will halve the current intensity, and so on.

The statement may be transformed to read thus: the resist-

ance is equal to the electromotive force divided by the current. In algebraic form this is expressed as—

$$R = \frac{E}{I}$$

Following out the same system of interpretation, we deduce the facts that with constant current, the resistance varies with the electromotive force, and that with constant electromotive force the resistance varies inversely with the current, and the current inversely with the resistance.

The last case represents the condition of parallel lighting work. By turning on lamps, the resistance of the circuit is lowered. The plant we may assume to be so organized as to maintain a constant voltage, therefore we know from Ohm's law that the more lamps we light, thereby reducing the resistance, the more current will be used in inverse proportion to the resistance.

Finally, Ohm's law may be stated thus: The electromotive force is equal to the resistance multiplied by the current intensity, in algebraic form—

$$E = R\,I.$$

This states that with constant resistance the current intensity varies with the electromotive force, and that with constant current intensity the electromotive force varies with the resistance.

Examples of Ohm's Law.—Assume an electroplating bath to be worked at a fixed resistance, and we wish to increase the amperage of the current passing through it. The voltage must be increased, because $I = \frac{E}{R}$, and we have assumed that R is invariable. Assume that a number of lamps are placed in series, and that each one requires the same current. If the number is increased, the resistance of the circuit will be increased. To keep the current constant, the electromotive force must be increased, because $I = \frac{E}{R}$, and if R is increased, E must also be increased, or else the value of the fraction $\frac{E}{R}$, and consequently

the value of I, will change. The form $E = R I$ could be well used here.

An example may be given of what may be termed a fallacious case, where Ohm's law seems to fail but does not.

Assume a battery of a considerable number of cells connected in series through a circuit of slight resistance. If the number of cells is doubled, and they are kept in series, the electromotive force will be doubled. While only a very slight increase of current through the circuit will be produced, yet the voltage or electromotive force has been doubled.

The fallacy of the deduction that this contradicts Ohm's law lies in the neglect to consider the resistance of the battery. In doubling the number of cells, not only is the electromotive force doubled, but the resistance of the circuit is nearly doubled, so that only a trivial increase of current is produced.

Such cases are frequent, and generally as simple as the above.

Five Forms of Ohm's Law.—The law can be stated in five forms, three as given—

$$I = \frac{E}{R}, \quad R = \frac{E}{I}, \quad E = R I;$$

and the following two—

$$\frac{R}{E} = \frac{1}{I} \text{ and } \frac{I}{E} = \frac{1}{R}$$

The first three are those most used; the first one is more used than any of the others. The first group should be memorized if possible.

Importance of Ohm's Law.—The consensus of opinion of instructors in electrical engineering would probably be to the effect that good work has been done if in a three years' course Ohm's law is well instilled in all its bearings into the student's mind. It is infallible and universal; it has no exceptions. Its action may be limited or obscured by other reactions, but it is always in force in electrical circuits. It binds together firmly the three factors of an active electrical circuit.

Sir Isaac Newton held when young that there should be no need of studying geometry; that to a properly developed mind it should be obvious. The simplicity of Ohm's law given in the three algebraic forms, with the verbal statement of each and

the various interpretations, tell all there is of it. But the student of electricity cannot exercise himself too much upon it. Reading over these few paragraphs should not be considered equal to the acquirement of Ohm's law.

Power. —The product of volts by amperes gives the unit of rate of energy, which is power. From the first and third forms of Ohm's law we get values for I and E respectively—

$$I = \frac{E}{R} \text{ and } E = R\,I.$$

Multiplying the first equation by E and the second by I, we have

$$E\,I = \frac{E^2}{R} \text{ and } E\,I = R\,I^2$$

This gives as the expressions for electric energy:

$$\frac{E^2}{R},\ R\,I^2 \text{ and } E\,I$$

The first states that with constant resistance the energy rate or power varies with the square of the electromotive force. The second states that with constant resistance the energy rate or power varies with the square of the current. Other interpretations less useful or at least less used are that with constant electromotive force the energy rate or power varies with the current, inversely with the resistance, and with constant current varies directly with the resistance.

Examples.—To increase the energy on a circuit operated by a very high resistance generator or battery, the resistance must be lowered. Such a circuit works at approximately constant voltage. To increase the energy on a constant current circuit, the resistance must be increased. The first statement is of merely theoretical value, for the increase of energy will be through the entire circuit, and all that in the battery is of no economic value. Lowering the resistance in this case throws energy into the battery. In the other case, increasing the resistance makes the proportion of energy absorbed by the battery or dynamo less.

As electric energy is distributed in practice, the law most quoted is to the effect that energy varies with the square of the current. The statement is incomplete unless it states that for it to be true the resistance must be constant.

The great problem which the engineer has to solve is the localization of energy. The energy absorbed in a battery or other generator is lost as far as utility is concerned. The same is to be said of that expended on the transmission line.

Constant Current Circuit.—Ohm's law $E = R I$ states that with constant current the electromotive force varies directly with the resistance. If a fixed current is passing through a circuit, the energy rate $I E$ in any part will be increased by increasing electromotive force expended on that part. Ohm's law as given above states that to increase this, the resistance of that part must be increased.

But the energy localized by the increase of resistance is heat energy, and such energy is only desired in certain things, such as lamps; in motors, heating is undesirable from several points of view. It indicates low efficiency, and may do injury. The use of the drop system solves the distribution of energy for all cases on an active circuit, when uncomplicated by special circumstances. The general law is this: Concentrate the drop of potential where the energy is to be utilized. A motor produces a drop by its counter electromotive force and resistance. The drop due to the first cause is useful, that due to resistance is useless. Energy expended on the resistance is wasted.

A typical constant-current circuit is an arc lamp series system. To increase the energy rate on the outer circuit, resistance must be added; the more lamps there are in series, the more energy will be expended. To add resistance so that the energy will be of use, lamps are added in series. To prevent waste of energy on the line, it is made of size sufficient to give low resistance compared to that usefully contained in the lamps.

Constant Potential Circuit.—The constant potential circuit is next to be considered. Let a fixed difference of potential be maintained at the terminals of any apparatus. The formula energy rate or $I E = \frac{E^2}{R}$ states that with constant electromotive force the energy rate varies inversely with the resistance. To develop energy in any appliance whose terminals are kept at constant potential, its resistance must be lowered.

A typical constant-potential system is a parallel circuit incan-

descent lamp system. On this, to increase the energy expended more lamps in parallel are put in operation, thus reducing the resistance. But it is interesting to note that for each number of lamps in operation, this becomes a constant current circuit. Therefore it is subject to the general law that resistance must be concentrated where heat energy is to be utilized. In this case it is in the lamps. The mains and feeders carrying the current to the lamps should be as large as is consistent with the requirements of capitalization.

Drop and Fall of Potential indicate the electromotive force expended on any part of a circuit. Thus a 50-volt incandescent lamp has a drop of 50 volts when burning. The terms are synonyms of Potential Difference. Drop may, as in an incandescent lamp, be due to resistance, or. as in an arc lamp, partly to counter electromotive force.

R I Drop and Counter E. M. F.—The first is the fall in potential brought about by resistance. By Ohm's law such drop is expressed by the equation $E = R\,I$. Without a current there is no R I drop; with a given electromotive force the drop varies with the resistance, and is equal to the product of resistance by current strength. This drop is to be distinguished from that produced by counter electromotive force. In charging a storage battery, each cell gives between two and three volts counter electromotive force, and this is almost independent of current strength. This produces a drop which is a counter electromotive force drop.

The drop of 110 volts in an incandescent lamp is an R I drop as far as is known; in an arc lamp, the drop is supposed to be a combination of a counter electromotive force and R I drop.

To determine the R I drop, the resistance R of the portion of the circuit in which it is to be developed is multiplied by the current strength I; the result is the R I drop in volts. Thus the R I drop of a 220-ohm lamp passing ½ ampere of current is $220 \times \frac{1}{2} = 110$ volts.

Examples of Power Calculations.—We have seen that the energy exerted by a current through a given resistance is expressed by any of the following expressions:

$$I\,E = \frac{E^2}{R} = R\,I^2$$

The last expression shows that the heating or mechanical equivalent of a current passing through a fixed resistance is proportional to the square of the current. This can be very simply shown by assuming that lamps are to be lighted.

Let each lamp be of 100 volts—200 ohms standard. Such a lamp will require by Ohm's law $I = \frac{E}{R} = \frac{100}{200} = 0.5$ ampere of current. If we double the current, we have enough for two lamps in parallel. Two lamps in parallel have half the resistance of one lamp. To get our original resistance, we must put two lamps in series and two in parallel. Double the original current will light these four lamps, giving four times the watts as before. By similar process we will find that to take three times the current without changing the resistance, three lamps in series and three such series in parallel will be required, giving nine times the number lighted by three times the current. Therefore the lamps which can be lighted by currents vary with the squares of the currents at constant resistance.

The lighting of a single lamp exacts a definite amperage and voltage. Keeping the amperage constant and varying the resistance, it is to be determined how a change in voltage will affect the light given on a portion of the circuit. Here the law of the square does not hold. If we have a 100-volt lamp requiring half an ampere of current and double the voltage, the lamp would give an immensely high illumination, and would burn out in a very short time. If the voltage were doubled, it would be necessary to take care of the increase by putting another lamp in series with the first. The current would remain one-half ampere, but for the double voltage only double the lamps would be lighted.

There is no contradiction involved in these two cases. A watt is the product of first powers of electromotive force and current, and the lamps lighted vary with the watts. In the first case, by placing the lamps in parallel the current was increased as many times as there were parallel series of lamps. To keep the resistance the same, as many lamps had to be placed in series as were in parallel. This multiplied the voltage by a multiplier expressing the number of lamps in series or in parallel, both

being the same. To get the watts expended on the lamps in the first case, the amperes had to be multiplied by the lamps in parallel to get the increased current intensity. The number of lamps in series gave a figure by which the voltage had to be multiplied to give the new voltage. Take the case of three lamps in parallel and three in series, and call the amperes and volts for a single lamp i and e respectively. The watts for a single lamp will then be indicated by $e\,i$. There are three lamps in parallel, so the new amperage will be $3\,i$. But there are also three lamps in series, in order to keep the resistance the same as with one lamp. The voltage therefore for the nine lamps arranged as described is $3\,e$. The product of the new voltage by the new amperage is—

$$3\,e \times 3\,i = 9\,e\,i,$$

or nine times the watts required for one lamp.

Taking the expression for electric power $\frac{E^2}{R}$ if it is interpreted for fixed resistance, then the power at fixed resistance will vary with the square of the electromotive force. This is the case with the nine lamps. The electromotive force was trebled, the resistance was kept constant, and nine times the watts resulted.

To keep the resistance constant, both voltage and amperage had to be increased in precisely similar ratio. There is no contradiction involved.

Calculation of Resistance of Parallel Circuits.—Suppose three conductors each of 10 ohms resistance are placed in parallel. The combined resistance will be one-third that of a single circuit. A bridge three planks wide will be only one-third the obstacle to the passage of a crowd that a bridge one plank wide would be. The combined resistance of the three circuits is expressed by $10/3 = 3.33$ ohms.

Assume that the three conductors are not of the same resistance. Let one be of 5 ohms, another of 3 ohms, and the third of 2 ohms resistance. The combined resistance is found by adding the reciprocals of the resistances and taking the reciprocal of the sum. The reciprocal of a number is the quotient of 1 divided by the number; the reciprocal of a fraction is the new

fraction having the denominator of the old fraction for numerator and the numerator for denominator. The reciprocal of 3 is 1/3; the reciprocal of 3/4 is 4/3. The reciprocals of the resistances of the three conductors are 1/5, 1/3, and 1/2, and the sum of these three fractions is 31/30, and the reciprocal of this sum is 30/31 ohm, the resistance of the parallel conductors.

Examples of R I Drop Calculations.—The R I drop is equal to the product of the resistance by the current. A 16-candle-power lamp rated to pass ½ ampere of current has a resistance of 220 ohms, and $220 \times \frac{1}{2} = 110$ volts, which is the drop. The formula for the drop is $E = R\,I$. R I drop varies with the current for fixed resistances.

Take three conductors of 5, 3, and 2 ohms resistance, and assume that a current of 16 amperes is to pass through them. What is the drop? The resistance of the three parallel conductors has been calculated as 30/31 ohms; the current is 16 amperes. The drop is $R\,I = 30/31 \times 16 = 480/31 = 15.48$ volts $= E$.

By means of the drop the current passing through each one can be calculated by Ohm's law, $I = \frac{E}{R}$. For the 5-ohm conductor it is $15.48/5 = 3.096$ amperes; for the 3-ohm conductor, $15.48/3 = 5.16$ amperes; for the 2-ohm conductor, $15.48/2 = 7.74$ amperes. As a proof of the correctness of the figures, the three currents thus determined may be added, when they should give a sum of 16 amperes within the limits of the decimal places to which the operation was carried out: $3.096 + 5.16 + 7.74 = 15.996$ amperes.

Example of Counter Electromotive Force Drop Calculation.—A drop may be caused by a counter electromotive force. One battery in opposition to another may give the latter. Suppose a battery of seventeen Daniell's cells of 1.06 volts each is working against a smaller battery of six similar cells, what is the drop? It is $6 \times 1.06 = 6.36$ volts, and the working electromotive force on the system is equal to the difference of the electromotive forces of the two batteries. The first battery has an electromotive force of $17 \times 1.06 = 18.02$ volts, and $18\,02 - 6.36 = 11.66$ volts—the net or working electromotive force. Such a drop

is usually accompanied by a drop due to resistance. The resistance drop varies with the current; the counter electromotive force does not necessarily.

Kirchhoff's Laws.—These are extensions of Ohm's law, and are two in number. The first states that if any number of conductors meet at a point, and if all the currents flowing to the point are treated as positive, and those flowing away from it are treated as negative, if the potential at the point remains constant, the algebraic sum of the currents will be zero. The second law states that in a network of conductors forming a closed polygon, with currents flowing through its members, the algebraic sum of the products of the currents by the resistances for all the conductors is equal to the sum of the electromotive forces.

Conductance and Cross-Sectional Area of Conductors.—The conducting power of a conductor for electricity, or its conductance, varies with its cross-sectional area. A wire of one-tenth of an inch cross-sectional area has one-half the conductance of a wire of two-tenths of an inch cross-sectional area. This is true only when the wires are of the same material. Electric conductors are generally of circular section. The areas of two circles of different diameters vary with the squares of the diameters. A wire four one-thousandths of an inch in diameter has sixteen times the cross-sectional area, and consequently sixteen times the conductance or conducting power, and one-sixteenth the resistance, of a wire one one-thousandth of an inch in diameter.

Circular Mil System.—The circular mil system is based on the considerations stated above. It is a system of stating the size of electrical conductors, based upon the cross-sectional area of a standard circular electric conductor, and has obtained universal acceptance among American engineers.

The length of one one-thousandth of an inch is a linear mil, or simply a mil. The area of a circle one one-thousandth of an inch in diameter is one circular mil.

The unit of the system is the circular mil.

A wire of copper of commercial purity, one foot long and one circular mil in cross-sectional area, has a resistance of 10.79 ohms at a temperature of 75° F. (24°— C.) This is a wire of one one-thousandth of an inch diameter.

Application.—If we know a wire's cross-sectional area expressed in circular mils, we can determine its resistance by simple division. Resistance varies inversely as the cross-sectional area of a conductor. Therefore, if the resistance of a wire of one circular mil cross-sectional area is divided by the circular mils in the cross-sectional area of another wire of identical length, the quotient will be the resistance of the latter wire.

Thus a wire one foot long and nine circular mils in area has one-ninth the resistance of a wire one foot long and one circular mil in area. In ohms the resistance of the larger wire is $10.79/9 = 1.199$ ohm.

As the cross-sectional areas of wire vary with the squares of their diameters, a wire 3 mils in diameter has nine times the area of a wire one mil in diameter.

To determine the cross-sectional area of a wire in circular mils, square the diameter expressed in linear mils or one one-thousandths of an inch.

A wire of 1/20 of an inch in diameter is 50/1000 of an inch in diameter. Its cross-sectional area therefore is $(50)^2 = 2500$ circular mils. The resistance of one foot of such wire, if of copper, is $10.79/2500 = 0.00004316$ ohm.

Area of a Circular Mil.—The area of a circular mil is 0.000000785 square inch.

As the circular mils in the cross section of a circular wire are equal to the square of its diameter expressed in one-thousandths of an inch, the expression "square of the diameter" may be taken as the synonym of "circular mils," if the diameter is expressed in one-thousandths of an inch or mils.

Examples.—Owing to the facts that commercial copper varies greatly in purity, and that very small amounts of impurity affect its conductivity to a considerable degree, there is nothing final about the figure 10.79 ohms given as the resistance of a foot of wire one circular mil in cross-sectional area. Thus Roebling gives 10.51 ohms, at 75° F. (24° — C.) and 10.18 ohms at 60° F. (15°+ C.) as the resistance of a foot of one circular mil wire.

Accepting Roebling's figures, the use of circular mils may be illustrated by some calculations.

A wire is 1075 feet long, and is 0.081 inch diameter. What is its resistance?

0.081 inch is 81 mils. A wire of 81 mils diameter has a cross-sectional area of $(81)^2 = 6591$ circular mils. The resistance of the wire is $1075 \times 10.51 \div 6591 = 18.896$ ohms.

A wire is 1100 feet long and has a resistance of 4.404 ohms. What is its diameter?

Its cross-sectional area is expressed by the formula—

$$1100 \times 10.51 \div 4.404 = 2625.1 \text{ circular mills.}$$

The diameter in one-thousandths of an inch is equal to the square root of 2625.1.

$$\sqrt{2625.1} = 51.233 \text{ mils or } 0.051233 \text{ inch.}$$

Wire Gauges.—Various wire gauges are in use. A wire gauge is based upon a series of cross-sectional areas of wires. Each size of such wires is designated by a number. The numbers ordinarily are consecutive, the lower the number the larger is the wire; thus No. 1 wire is larger than No. 2, and is smaller than No. 0. If the sizes are to be extended beyond 1, the designations are No. 0, No. 00, No. 000, and so on.

American Wire Gauge.—The wire gauge generally used in the United States for copper wire is the Brown & Sharpe gauge, usually written "B. & S. wire gauge," or sometimes simply "American wire gauge." At first sight it seems a purely arbitrary scale, but it is not. It is fair to assume that anyone making calculations of resistance of conductors will have the table to refer to. But there are a few figures which, if remembered, will enable one to operate without the table and yet to express the size of wire in the B. & S. gauge with a close approximation to truth.

No. 10 wire is approximately 0.100 inch or 100 mils diameter, with a cross-sectional area of 10,000 circular mils. Its resistance per 1000 feet is 1 ohm approximately.

The cross-sectional area of a wire of any number in the B. & S. gauge is approximately 1.26 times greater than the one below it. Thus the circular mils of No. 9 wire are equal to those of No. 10 wire, 10,000, multiplied by $1.26 = 12{,}600$ circular mils approximately. The circular mils of No. 8 wire are equal to $12{,}600 \times 1.26 = 15{,}876$ circular mils. The circular mils of No. 7 wire are equal to $15{,}876 \times 1.26 = 20{,}003$ circular mils. All these are close approximations to truth.

This brings out another feature. A wire three numbers away

from another wire has about double its cross-sectional area if of lower number. Thus, taking 10,000 circular mils as the cross-sectional area of No. 10 wire, we have No. 7 wire, three numbers lower. Its cross-sectional area is twice that of No. 10 wire, or $10{,}000 \times 2 = 20{,}000$ circular mils. No. 4 wire is three numbers lower than No. 7. Its cross-sectional area is $20{,}000 \times 2 = 40{,}000$ circular mils.

From the above it follows that by going to higher numbers for a difference of three numbers, we must divide by 2. Thus, No. 13 wire is three numbers higher than No. 10. Its cross-sectional area is equal to $10 \div 2$, or 500 circular mils. No. 16 wire is three numbers higher than No. 13 wire. Its cross-sectional area therefore is equal to $5000 \div 2 = 2500$ circular mils.

These figures are only approximate, but are well within practical limits. The following give the true cross-sectional areas of numbers differing by 3 and those determined by the approximate method.

B. & S. GAUGE.

1. No. of Wire.	2. Areas in Circular Mils. True.	3. Areas in Circular Mils. Approximate.	4. Approx. +4 Per cent.	5. Errors in Col. 4 Per cent.
000	168,100	160,000	166,400	1.02
1	83,521	80,000	83,200	0.40
4	41,626	40,000	41,600	0.06
7	20,736	20,000	20,800	0.31
10	10,404	10,000	10,400	0.04
			+3%	
13	5,184	5,000	5,150	0.62
16	2,601	2,500	2,575	1.00
19	1,296	1,250	1,288	0.62
22	640.1	625	644	0.61
25	320.4	312.5	321.9	0.46
28	158.8	156.2	160.8	1.26
31	79.2	78.1	80.4	1.52
34	39.7	39.0	40.2	1.26

The error in the above approximate process it will be seen varies from less than 2 per cent to over 4 per cent. If for wires

larger than No. 10, 4 per cent is added to the approximate sizes, and if for wires smaller than No. 10, 3 per cent is added, the results will be well within working limits. This is done in the fourth column of the table, and it will be seen that the error is generally less than 1 per cent. For No. 000 wire it is 1.022 per cent; for No. 10 wire, it is 0.04 per cent; for No. 34 wire, it is 1.26 per cent.

To find the size of intermediate numbers, multiply the circular mils of wire of any number by 1.26 to get the circular mils of the next larger wire. Thus, the size of No. 3 wire is obtained approximately by multiplying the circular mils of No. 4 by 1.26.

$41{,}600 \times 1.26 = 52{,}416$ circular mils, the size of No. 3 wire.

Multiply the circular mils of wire of any number by 1.60 to get the circular mils of the second next wire. Thus, the size of No. 2 wire is obtained approximately by multiplying the circular mils of No. 4 by 1.60.

$41{,}600 \times 1.60 = 66{,}560$ circular mils, the size of No. 2 wire.

The sizes of No. 3 and No. 2 wire given in the table are 52,634 and 66,373 circular mils. The degree of approximation is very good. Especially is this true when it is remembered that no two samples of copper have the same conductivity, and that the temperature variation is considerable in copper.

The figure 1.26 is the cube root of 2. The figure 1.60 is 1.26×1.26.

CHAPTER V.

ELECTRO-CHEMISTRY.

The Basis of Electro-Chemistry.—When one coulomb of electricity passes through water, it liberates 0.0105 milligramme of hydrogen. The chemical equivalent of hydrogen is 1, that of oxygen 16. In one molecule of water there are 2 atoms of hydrogen and 1 atom of oxygen, or by weight 16 parts of oxygen and 2 parts of hydrogen, a total of 18 parts by weight. The 0.0105 milligramme of hydrogen was derived from a certain quantity of water, which bears the same proportion to 0.0105 that the chemical equivalent of the water molecule, which we have seen is 18, bears to the sum of the equivalents of hydrogen in its molecule, which are 2. This gives us the proportion:

$$2 : 18 :: 0.0105 : x = 0.0945 \text{ milligramme water.}$$

Hydrogen Liberated by the Coulomb.—This tells us that one coulomb of electricity decomposes 0.0945 milligramme of water. Not only is hydrogen set free, but oxygen also. The oxygen can be got by a similar proportion, based on the proportion of hydrogen to oxygen in the water molecule, which as we have seen is 2 to 16.

$$2 : 16 :: 0.0105 : x = 0.0840 \text{ milligramme oxygen.}$$

This result could have been more simply reached by subtracting the hydrogen liberated from the water decomposed.

$$0.0945 - 0.0105 = 0.0840 \text{ milligramme oxygen.}$$

Every element is liberated from a compound in strict proportion to the coulombs which pass through it by electrolytic conduction.

Proportion of Hydrogen to Oxygen.—We have seen that one coulomb liberates different quantities of oxygen and hydrogen.

Hydrogen has a chemical equivalent 1/16 that of oxygen. Yet a coulomb liberates only eight times as much instead of sixteen times as much. This is because oxygen is a dyad, which means an element of double combining values, which is its valency, and hydrogen is one of single combining value, a monad.

To get the relative amount of oxygen liberated for a given amount of hydrogen, we might have divided its chemical equivalent by 2, the figure of its valency, and put our second proportion directly thus:

$$1 : 8 :: 0.0105 : x = 0.0840 \text{ milligramme oxygen.}$$

Atomic Weights and Chemical Equivalents.—In any chemistry will be found a table of atomic weights and sometimes of chemical equivalents. If the table is properly arranged, each element's valency will be stated. If this information is omitted from the table, it can be found in the text of the book. To find how much of any element will be separated from its combination by a coulomb of electricity, divide its atomic weight by its valency, and multiply by 0.0105.

Electro-Chemical Equivalents.—Numbers thus obtained are called electro-chemical equivalents. Suppose the electro-chemical equivalent of nickel is required. The atomic weight of nickel is 58.8, its valency is 2, or it is a dyad or is a bivalent. These are three ways of expressing the same fact. We divide its atomic weight by its valency, and multiply the result by the electro-chemical equivalent of hydrogen:

$$(58.8 \div 2) \times 0.0105 = 0.3087 \text{ milligramme}$$

which is the electro-chemical equivalent of nickel, or the quantity which one coulomb can separate from a solution.

If gold is in question, we find its atomic weight to be 197 and its valency 3. Its electro-chemical equivalent is given by the equation:

$$(197 \div 3) \times 0.0105 = 0.6894 \text{ milligramme}$$

which is the electro-chemical equivalent of gold.

If an electro-plater is paying for his electricity by the ampere-second, or, what is the same, by the coulomb, it is of importance for him to know how much his plating costs him in electric current. This he finds out from the electro-chemical equivalent

of the metal he is depositing and the total weight which he deposits.

Current Strength and Chemical Decomposition.—The electro-chemical equivalent of silver is 1.134 milligramme. If the strength of a current given by a battery is to be determined, it may be passed through a solution of silver for a known number of seconds. The silver which it separates is weighed, the weight is divided by the seconds of time during which it passed and by the electro-chemical equivalent of silver. The result is the strength of the current in amperes.

Silver Voltameter.—The apparatus outlined above is one of the classics of electricity, and is known as the silver voltameter.

Summary.—The statements just given may be conveniently summarized.

The weight z of an element set free by one coulomb of electricity, calling atomic weight A W and valency V l, is given by the equation:

$$z = \frac{A\,W}{V\,l} \times 0.0105 \text{ milligramme.}$$

A current of intensity I will deposit a weight P of an element per second according to the equation:

$$P = z\,I = \frac{A\,W}{V\,l} \times 0.0105 \text{ milligramme.}$$

One ampere hour is equal to 3600 coulombs; it will therefore liberate $3600 \times 0.0105 = 37.8$ milligrammes of hydrogen, and $\frac{A\,W}{V\,l} \times 37.8$ of any other element.

This is stated very simply. Those who are interested in electro-chemistry should study up the theory of chemical equations and of chemical arithmetic (stoichiometry) also.

Example.—A chemical equation may be now written out, and the electro-chemical equivalents calculated. A bath of copper sulphate has a current of 9 amperes passed through it for 35 minutes; how much copper and sulphuric acid will be produced?

The chemical formula for copper sulphate is $CuSO_4$, for sulphuric acid H_2SO_4, for water H_2O. The decomposition is expressed by the chemical equation:

$$CuSO_4 + H_2O = Cu + H_2SO_4 + O.$$

The nascent oxygen would usually be caused to attack an anode, but for our purposes we will assume that it escapes.

The atomic weights needed are the following: Copper, Cu, 63; sulphur, S, 32; oxygen, O, 16; hydrogen, H, 1. Copper is a dyad.

The copper precipitated by a coulomb is—

$$\frac{63}{2} \times 0.0105 = 0.3307 \text{ milligramme.}$$

35 ampere minutes is equal to $60 \times 35 = 2100$ coulombs. The 35 ampere minutes will precipitate $0.3307 \times 2100 = 694.47$ milligrammes of copper. The molecular weight of the sulphuric acid is obtained by adding together the atomic weights of its constituents. These weights are $2 + 32 + 64 = 98$; and for every 63 parts of copper precipitated, 98 parts of sulphuric acid are set free. This gives for the total sulphuric acid the proportion:

$63 : 98 :: 694.47 : x = 1080$ milligrammes sulphuric acid.

Electromotive Force in Chemical Decomposition.—Electromotive force does not enter into these calculations. It requires a definite amount of electromotive force to break up each chemical combination. For some of them it varies exceedingly little; if it varied more, it could be used as a basis for methods of chemical separation in analysis.

Energy in Chemical Decomposition.—As electromotive force is required to break up an electric combination; and as the quantity decomposed or broken up varies with the coulombs, the energy expended varies with both these factors, and the energy rate or power with the volt-amperes or watts. Watts multiplied by seconds give volt-coulombs, and watt-seconds or volt-coulombs multiplied by 10,193.7 gives gramme-centimeters of energy. Calling coulombs Q and electromotive force E, we have for the energy expended in a chemical decomposition expressed in mechanical units of weight and height:

$Q\,E \times 10{,}193.7$ gramme-centimeters and $Q\,E \times 0.101937 =$ kilogramme-meters.

The energy expended in decomposition is here expressed in pure mechanical units. The weight of substance decomposed by Q coulombs from what we have seen is $Q\,z$.

The energy expended may also be expressed in heat units, say in grammes of water heated 1° Centigrade, or calories, some-

times called small calories. The mechanical equivalent of heat is 0.424 kilogramme-meter per calorie. The weight of the substance Q z multiplied by the calories H t corresponding thereto and multiplied by 0.424 will give kilogramme-meters of energy, the expression being 0.424 Q z Ht.

This has the same value as the other expression; they can be equated thus:

$$0.424\ Q\ z\ H\ t = 0.101937\ Q\ E,$$

which reduced so as to give the value of E by successive steps is—

$$E = \frac{0.424}{0.101937}\ z\ H\ t = 4.16\ z\ H\ t.$$

The above equation gives the value of E, or the electromotive force required to decompose a compound. We must know z, which is in grammes 0.0000105 (= 0.0105 milligramme) and H t, which is the heat of combination or the thermo-chemical equivalent of the compound dealt with.

The quantities of heat expressed in thermal units are termed thermo-chemical equivalents. They have been determined for a great many chemical combinations, and are expressed in gramme-degrees C. or kilogramme-degrees C. The above formula has been deduced for gramme-degrees. It is merely a question of where the decimal point shall be. If the equation is to hold for kilogramme-degrees, it must be shifted to represent one thousand times the quantity; 4160 must be substituted for 4.16 in the expression.

Voltage Calculations.—Suppose it is asked what voltage will be required to decompose water. Consulting the table, we find that one gramme of hydrogen in burning, i. e., in forming water, produces 34,450 gramme-degree calories. The electro-chemical equivalent of hydrogen is 0.0000105 gramme. Substituting in the equation we have:

$$E = 4.16 \times 0.0000105 \times 34{,}450 = 1.5047 \text{ volts.}$$

Thermo-chemical equivalents are expressed in two ways. One is the heat liberated by the combination of a gramme of the substance. The other is the heat liberated by grammes equal in number to the chemical equivalent of the substance. Sometimes one and sometimes the other is given in tables. If the

first is used in the calculation, the form of equation given for hydrogen is adhered to.

$$E = 4.16 \times \text{electro-chem. equiv.} \times \text{thermo-chem. equiv.}$$

If the latter is used, the factor 0.0000105 has to be retained. $4.16 \times 0.0000105 = 0.0000437$. This factor may be kept as a constant, and we have for the second form of thermo-chemical equivalents:

$$E = 0.0000437 \times \text{thermo-chem. equiv.}$$

Both give precisely the same result, but the second is the more usual and far more convenient form. An interesting point occurs in electro-plating. As each portion of metal is deposited, a definite quantity of energy is expended on its separation from the solvent. But for each such quantity of metal deposited an identical quantity is dissolved from the anode, with production of energy. One energy is equal to the other, so that theoretically all the energy required is that needed to overcome the resistance of the solution. In practical operation there is always a loss besides this. Where a metal is precipitated and none dissolved, the energy to decompose the salt goes to the expense account.

Many battery calculations have been made to determine the voltage given by different combinations. The zinc-copper-copper sulphate couple (Daniell's battery) is thus calculated for its voltage. Zinc is dissolved, forming sulphate; this sets energy free or develops energy. Copper sulphate is decomposed, absorbing energy. Zinc combining with oxygen gives out 43,200 calories, and the oxide combining with sulphuric acid gives out 11,700 calories, a total of 54,900 calories. These figures are for the gramme equivalent of zinc, which is a number of grammes equal to its atomic weight 65.2 divided by its valency 2, or $65.2/2 = 32.6$ grammes.

The total calories of energy developed in calories are $43,200 + 11,700 = 54,900$.

The total calories of energy absorbed by the copper separated from the sulphate are $19,200 + 9200 = 28,400$ calories.

The net calories developed in the combination are $54,900 - 28,400 = 26,500$. For the electromotive force we have:

$$E = 0.0000437 \times 26,500 = 1.15 \text{ volts.}$$

CHAPTER VI.

PRIMARY BATTERIES.

The Primary Battery Cell.—The simplest types of primary battery come under the category of single-fluid cells. A piece of copper and one of zinc, if placed in contact with each other and immersed in a saline or acid solution, will generate a current of electricity due to the impressing of electromotive force upon the circuit formed by these things—the saline or acid solution, the copper, and the zinc. The circuit may be looked upon as a triangle—one side liquid, one copper, and one zinc.

If a cartridge shell contains some dilute acid, and a wire or rod of zinc is immersed in it, but not allowed to touch the copper, a galvanic battery is formed. Attach wires to the zinc and to the copper. Connect one to a plate buried in the earth and the other to a telegraphic instrument, and messages can be sent by it over many miles of wire. There is some claim that a battery made out of a percussion cap has sent an electric impulse across the Atlantic Ocean.

Three Constituent Parts.—In a cell there are three principal things as noted above. One is a liquid, the electrolyte, which will be decomposed, through attacking chemically a substance, almost always a zinc plate, when an electrical current is passing through it. The second element is the zinc plate or some equivalent solid or liquid material which the solution can attack. The other is a material which the solution cannot attack. The two materials last mentioned must be conductors of electricity.

Simple Batteries.—A glass tumbler of dilute sulphuric acid with a plate of zinc and one of copper (carbon or platinum and

some other metals will do) dipping into it and not touching each other constitutes a simple battery. If the zinc is pure, no action will take place until the metals are connected electrically by touching each other or by a conductor such as a copper wire. When such connection takes place, a current will flow and the zinc will be attacked. The amount of zinc attacked will be in exact proportion to the coulombs of electricity produced.

The plates of metal conduct the current by regular electric conduction. The liquid as such has hardly any true conducting power. A mere trace of conductivity can be found in it, by the production of very trifling currents, practically negligible. But under the influence of the electric current, the liquid is decomposed. In its decomposition it virtually becomes a conductor, and is said to conduct electrolytically. The solution is called an electrolyte, which word means "decomposed by electricity." Such a battery is shown in Fig. 19, in which the zinc plate is marked Zn, the copper plate Cu, and the direction of the current is indicated by arrows. The current, it will be observed, always flows from plus (+) points.

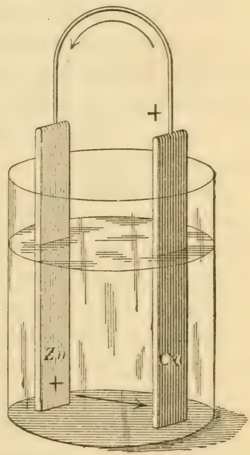


FIG. 19.—SIMPLE BATTERY.

Nomenclature.—The general nomenclature of the parts of the cell is rather confusing, but it is hopeless for anyone to attempt to simplify it, because positive and negative are applied in diametrically opposite senses to the plates, and cathode, anode, electrode, plate, and other terms are embalmed in the literature of the science. In reading an author whose subject is at all understood, the reader will have no trouble in appreciating the particular terminology he uses. The simpler terminology is generally the better. Any kind of *memoria technica* or artificial memory may be used to keep clear the distinction between positive and negative.

Negative and Positive Plates.—Writers in the English lan-

guage usually call the plate corresponding to the copper plate of the simple battery described, which is the one unacted on, the negative plate. This is because it is not dissolved or attacked. The zinc plate, which is attacked, is then called the positive plate. The direction of current in the outer circuit, on the telegraph line or other conductor, is taken as from the negative plate to the positive plate. This may be remembered by picturing the unattacked plate as an inert collector of electricity, which it pours out upon the circuit in the form of current.

The above terminology is simple and readily remembered.

An excellent *memoria technica* is that the current starts from a plate the initial letter of whose name is generally *c* (carbon or copper) and goes through the outer circuit to a plate of initial *z* (zinc). The current starts from the letter which comes earlier in the alphabet.

While solid plates are almost invariably used, a liquid amalgam of zinc may represent the positive plate, and liquid mercury might be used to represent the negative plate. There is a battery in which the first-described arrangement exists.

There is one term which may be advantageously used; it is "electrode" for plate. Thus we can broaden the assertion above by saying that a battery may have indifferently solid or liquid "electrodes."

Cell, Couple, and Pair.—A battery of only two plates is called a cell, a couple, or a pair. An aggregation of cells becomes a battery. It is a case of the greater including the less. The word *pile* is often applied to a battery. Properly, this term should be restricted to the real literal voltaic pile described on pages 97 and 98.

Exhaustion and Polarization.—When the solution is weakened by dissolving the positive electrode, the battery is said to be exhausted. When the negative plate loses effect from accumulation of hydrogen, the battery is said to be polarized. The distinction between exhaustion and polarization should be followed closely.

Local Action and Amalgamation.—The essential thing in batteries is to avoid what is called local action in the zinc. Chemically-pure zinc is not attacked by dilute sulphuric acid

such as is used in batteries. But commercial zinc contains enough impurity to cause local action. This means that it forms a lot of little voltaic couples, and accordingly dissolves in weak acid. To prevent this, the zinc in all acid solution batteries is amalgamated with mercury. The mercury is rubbed over the clean surface of the zinc along with some dilute sulphuric acid. A strip of galvanized iron is an excellent rubber for amalgamating. It will pick up mercury as a soldering iron will pick up solder. Newly-amalgamated zinc shines like silver, but soon loses this luster. It is exceedingly brittle.

As a trace of zinc injures mercury, the plates should be amalgamated with a few drops of mercury only. Dipping them into mercury is unnecessary and the mercury thus abused has to be purified before it can be used for other purposes.

The first genuine primary battery dates back to the Italian physicist Volta in 1800. This is a good starting point for the description of batteries.

Volta's Battery.—This construction goes back over a century. It is adapted for a series of cells in series arrangement, which was called a "crown of cups," or *couronne des tasses*. A plate of zinc is soldered to a plate of copper at one end, so that the two form a sort of V or U. A number of these are made. Besides these double plates, two single plates, one of zinc and one of copper, are provided for the ends. Cups one greater in number than the pairs of soldered plates are partly filled with weak sulphuric acid. The soldered plates are put in, each pair in two cups, zinc in one and copper in the other, each cup receiving the zinc plate of one pair and the copper plate of the other pair. After all the soldered pairs of plates are disposed of, the end cups will each have one (*a*) a zinc plate and the other (*b*) a copper plate in it. The whole is then completed by putting into one cup (*a*) a copper single plate and into the other cup (*b*) a zinc plate. Care must be taken that the plates do not touch.

The electromotive force of the zinc-copper couple is less than one volt. It is of only historic interest.

Volta's Pile, or the Galvanic Pile.—A series of disks of copper and zinc are cut out of sheet metal. They may be some

inches in diameter. Half as many disks of bibulous pasteboard or of cloth are cut out. These must be about a quarter of an inch less in diameter than the metal plates. The pasteboard or cloth disks are moistened with acid. Any excess must be squeezed out. A piece of heavy glass is a good basis for the erection of the pile. This is laid on a table or elsewhere, and a disk, which we will assume to be of copper, is placed upon it. The pile may be started with zinc. On this is placed a disk of pasteboard or cloth. It must not be too wet. Next comes a disk of zinc, then one of copper, then pasteboard or cloth, and

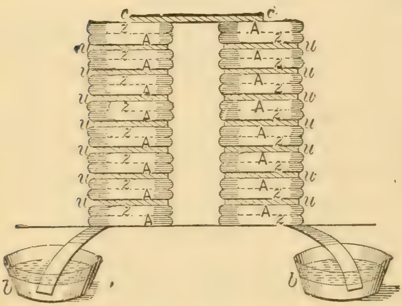


FIG. 20.—THE GALVANIC PILE.

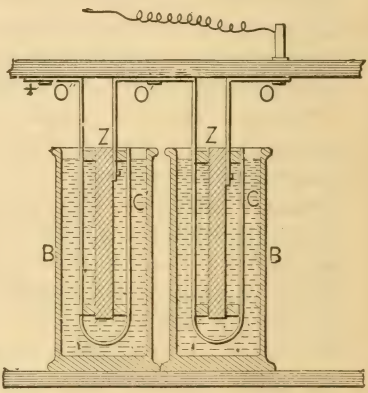


FIG. 21.—THE WOLLASTON BATTERY.

so on until fifty or one hundred plates have been used. The exciting solution may be water and sal ammoniac or a mixture of water and 1/20 its weight of sulphuric acid. The disks of cloth or pasteboard must not be so saturated as to permit the weight of the plates to squeeze out the acid. No acid must get upon the edges of the plates. Ears may be left on some of the disks, certainly upon the end ones, for attaching the wire of the circuit. If ears are provided on some of the intermediate plates, various voltages may be taken from it. An improvement is to solder the zinc and copper plates of each pair together, either over the entire face or accurately around the entire edge. The galvanic pile is mainly of historic interest. The cut, Fig.

20, shows a double column or pile. The zinc plates are marked *z*, the copper plates A, the cloth *u*. A bar *c c* connects them at top. It will be observed that the order of copper and zinc is reversed in the two columns. This keeps them in the same relation to the current. The terminals dip into two vessels of salted or acidulated water, *b b*, which can be used as terminals, by dipping other plates at the end of wires therein.

Wollaston's Battery.—This is a copper-zinc combination. The copper plate is bent into a U shape, and the zinc plate lies within its bends. In the cut, Fig. 21, C C are the copper plates, Z Z the zinc plates, B B the cups. Blocks of wood separate the plates at the bottom. Their connections are screwed to a wooden bar at the top. This with the wooden blocks keeps them fixed in position. The cut, Fig. 22, shows the plates with their terminals O O′.

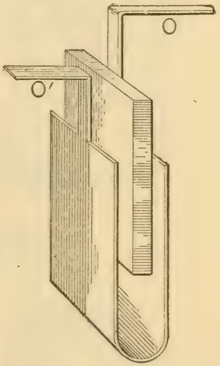


FIG. 22.—PLATES OF WOLLASTON'S BATTERY.

Hare's Calorimeter.—This is another historical battery devised by Offershaus in 1821 and modified by Hare in 1824. It is shown in the cuts, Fig. 23. A sheet of copper and one of zinc are wound into a spiral. Pasteboard strips are used to keep them from touching each other. They are dipped into a vessel of acid or sal ammoniac solution when to be used. Wire terminals are soldered to the zinc and copper respectively. Notched standards are provided, to carry the weight of the plates and to keep them out of the solution if desired. The zinc terminals are marked Zn and the copper ones Cu.

Zamboni's Pile.—A glass tube one-half to one inch in diameter is coated on the inside with sealing wax. It is filled with disks of silver paper coated on the back with powdered manganese dioxide rubbed up with thinned mucilage. The disks must dip in easily, so as not to get manganese dioxide on the inner surface of the tube. A pile of one thousand such pairs gives enough electromotive force to deflect a straw suspended by a silk filament. A pair of Zamboni's piles, each of some two thousand pieces of paper, are sometimes arranged to attract and discharge alternately a strip of gold leaf suspended electrometer

fashion by a filament. It is said that such a pendulum will oscillate for years.

Modern Batteries.—We now come to batteries which are more than historical. Some go back to early days, but are still used or have been used in modern days. These necessarily must, if excited by acid, be protected against polarization. A general division into two classes may be made, single-fluid and double-fluid cells. We shall first consider single-fluid cells.

Smee's Battery.—Zinc and platinized platinum or platinized silver in weak sulphuric acid. Modified by Patterson, who substituted platinized iron for the silver plate; by Grove, who substituted platinized wire gauze; by De St. Amstell, who substituted platinized tulle. Smee's battery has long been a prominent battery. The platinizing is not a simple plating with platinum, but platinum black, which is a very finely divided form of the metal, is deposited upon the surface by electro-deposition. This form of platinum cannot be covered by hydrogen; smooth

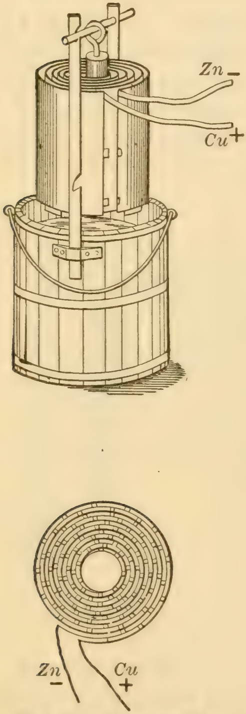


FIG. 23.—HARE'S BATTERY. (Deflagrator.)

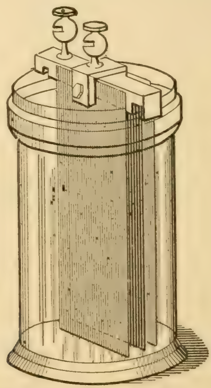


FIG. 24.—SMEE'S BATTERY.

platinum can be covered virtually by the gas, so as to polarize the battery. As usually mounted, a bar of wood separates the plates, whose upper edges are secured or clamped to it. The exciting fluid is sulphuric acid diluted with water. It may range from one-seventh to one-sixteenth its volume of acid, according to the requirements. The platinum plate before use is dipped every day into a solution of ferric chloride. This oxidizes any reduced deposit or occluded hydrogen. Silver-plated lead platinized is substituted sometimes for the regular negative electrode.

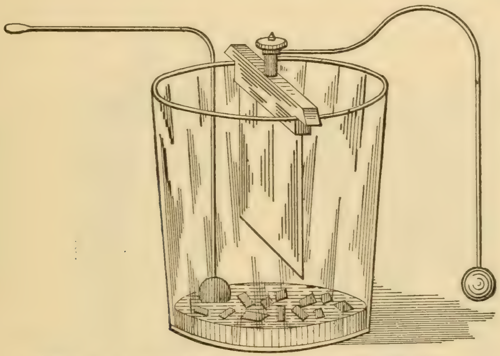


FIG. 25.—SMEE'S BATTERY—TYER'S FORM.

E. M. F., 0.42 to 0.47. This construction is shown in Fig. 24. Another form is shown in Fig. 25. Mercury is poured into each cell, and bits of zinc are dropped into it from time to time. Thus scraps of zinc can be used instead of a plate. A ball of zinc, cast on the end of a wire, which wire must be insulated, dips into the mercury. Walker (1859) used platinized carbon instead of platinized metal. E. M. F., 0.66.

Iron Negative Plates.—Sturgeon (1840) used cast iron; Münnich (1849) amalgamated iron; Callan (1845) cast iron in form of a shallow vessel, constituting at once the recipient for solution and the negative electrode. Hughes (1880) used zinc-hydrogenated iron, acidulated water; polarization only one-fifth that of Smee's battery. E.M.F., 0.56.

Aluminum Negative Plate.—Helot (1855) zinc-aluminium-

dilute sulphuric acid. The aluminium negative plate is dipped in strong hydrochloric acid for a few minutes to make it less easily polarized.

Grove's Battery (1838).—Zinc amalgam-platinum in a solution of sulphuric acid with nitric acid as a depolarizer. This has seen long service as one of the leading batteries of the world. The cut, Fig. 26, shows one construction. The platinum goes in a porous cup, V. This contains nitric acid, 1.33 sp. gr. Outside the porous cups is the zinc, Z, and the whole is contained in a battery jar charged with sulphuric acid. As it produces current

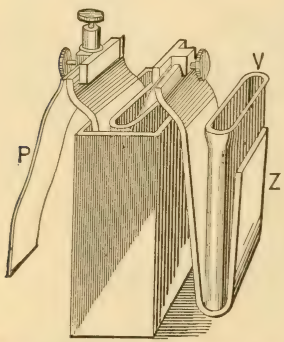


FIG. 26.—GROVE'S BATTERY.

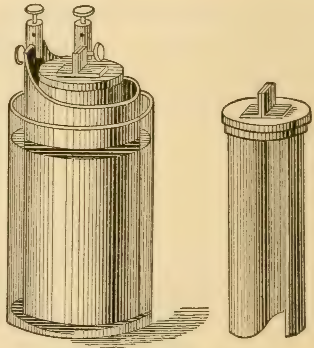


FIG. 27.—GROVE'S BATTERY.

the nitric acid is reduced, and corrosive and poisonous fumes of nitrogen oxides are evolved. It is credited with an electromotive force of 1.9 volts. Generally, less than this is to be looked for.

Another form of Grove's battery, in which a bent platinum plate is used to increase the area and diminish the resistance, is shown in Fig. 27.

Various modifications have been tried. Oxalic acid (Royer) has been used instead of nitric. The result was the production of formic acid with evolution of hydrogen. A saturated solution of ferric chloride with a little nitric acid has been recommended.

As long ago as 1840 (Hawkins) and 1841 (Olfers) the platinum was replaced by iron in concentrated nitric acid. Iron is not attacked by this acid when concentrated. The acid if diluted

attacks it, so this formed an objection to its use, as the acid soon becomes dilute by use of the battery.

Uelsmann proposed to substitute silicon iron for platinum in the Grove cell. The E. M. F. varied with the concentration of the nitric acid.

Buff (1857) proposed aluminium in place of the platinum.

Grove himself in 1839 had tried wood charcoal and retort carbon as substitutes for platinum. It is said that he thought that in the scientific world platinum only would be considered "truly in harmony with science."

Callan (1847) substituted platinized lead for the platinum, and replaced the nitric acid by a mixture of 4 parts concentrated sulphuric acid, 2 parts nitric acid, and 2 parts saturated solution of potassium nitrate.

Carbon Negative Plates.—Early in the last century Gautherot found that wood charcoal would act as a negative electrode in Volta's battery. The early inventors in this line were Leuchtenberg (1845), Fabre de Lagrange (1852), J. Walker (platinized carbon) (1859).

Tommasi (1881) used zinc-graphite in dilute sulphuric acid. The graphite is heated to redness, and cooled in a current of carbon dioxide or nitrogen. E. M. F. at first, 1.37 volts; falling rapidly to 1 volt, and after a few hours to 0.83 volt.

Moving Electrodes.—A number of batteries have the plates moved in and out of the solution, so as to depolarize the negative plate. Becquerel (1852) was an early investigator in this line. Erckmann made his plates disk-shaped, mounted them on an axle, and rotated them. About half their depth was immersed in the acid. Brushes rubbed against the plates as they rotated. Maîche (1864) devised a copper- or carbon-iron couple with very dilute nitric acid (one per cent). The copper or carbon electrode was disk-shaped and rotated as in Erckmann's battery, with about one-third its area immersed. Skene and Kuhmaier used a zinc copper cell with dilute sulphuric acid; the copper is moved in and out of the liquid by clockwork.

Bunsen's Battery (1842).—Amalgamated zinc carbon in dilute sulphuric acid mixed with fuming nitric acid as depolarizer. Bunsen improved on Grove's cell by substituting relatively cheap

carbon for platinum. E. M. F., 1.89 volts. He placed the zinc in the porous cup and the carbon in the exterior vessel. Archereau reversed the relation of the plates, and put the carbon in the porous cups and the zinc outside. The battery has been elaborately tested by Meylan (1886) with the following results:

Exciting liquid, sulphuric acid consisting of equal volumes of 60° Beaumé sulphuric acid and water. Depolarizer, nitric acid of 36° Beaume. Zinc, active surface 116.25 square inches. External resistance, 1.27 ohms. Internal resistance, 0.04 ohm, falling to 0.035 ohm and rising to 0.12 ohm.

	Electromotive force.	Current.	Energy.
Starting..............................	1.93 volts.		
After 15 minutes closed circuit......	1.87 "	1.42 amperes.	
" 24 hours " "	1.77 "	1.33 "	56 watt hours.
" 30 " " "	1.73 "	1.24 "	70 "

A modern Bunsen battery is shown in Fig. 28, the carbon and zinc plates being indicated by C and Z, and positive and negative by the regular signs + and —.

The Bunsen and Grove cells have the advantage that no salts are used in their solutions, so there is no trouble with crystallization in the carbon or platinum compartment. The evolution of nitrous fumes corroding the battery connections and exacting special ventilation is a very bad feature.

Modifications of Bunsen's Battery.—Numerous attempts have been made to modify it. A few only will be mentioned here.

Liais and Fleury (1852) made a carbon cup act at once as the porous cup and as the negative electrode. The nitric acid was poured into its interior. Miergles (1868) and Faure (1880) proposed a stoppered carbon bottle to hold the nitric acid and act as negative electrode. Boettger (1868) used carbon soaked in nitric acid as negative electrode. To suppress the fumes of the depolarizer Balsamo advised maintaining a layer of turpentine on top of the nitric acid. This suppresses a great deal of the emanation and suffers change in its own composition. Archereau suggested the use of tin scrap contained in a vessel inverted over the cell to combine with the nitrogen oxides. Rousse used a layer of oleic acid to absorb the fumes. Thann used as depolarizer a mixture of 500 grammes nitric acid to 60 grammes chlorochromic acid ($Cr_2\ O_2\ Cl_2$). The latter is obtained by acting on

10 parts potassium bichromate and 17 parts of sodium chloride with 30 parts concentrated sulphuric acid. It absorbs the nitrogen oxide fumes.

Gibbs' Battery.—Prof. Wolcott Gibbs in 1878 produced a truly philosophical modification of the depolarizing liquid in the Bunsen battery. He used as depolarizer nitric acid of 1.4 sp. gr. saturated with ammonium nitrate. This solution gives off innocuous nitrogen, as it is reduced by the nascent hydrogen.

Poggendorff's Battery.—This is one of the leading batteries.

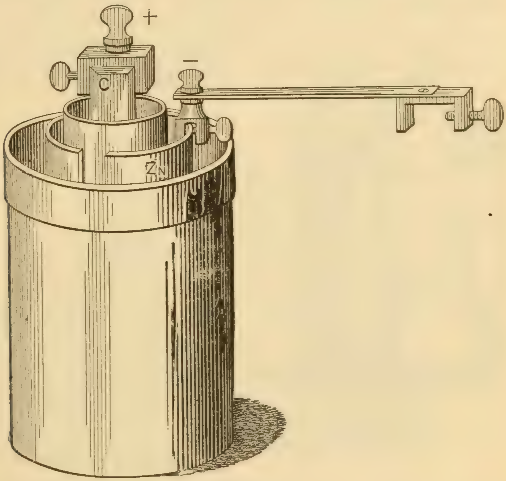


FIG. 28.—BUNSEN'S BATTERY.

It resembles closely the Bunsen battery, and dates back to 1842, the same year that Bunsen's battery is referred to. It is a zinc-carbon couple with porous cup and as an exciting liquid salt solution or dilute sulphuric acid. Its depolarizer is a solution of potassium bichromate. The latter oxidizes the nascent hydrogen, so as to prevent depolarization, and gives off no gas or fumes.

By using dilute sulphuric acid as the excitant, and a strong solution of potassium bichromate in dilute sulphuric acid as the depolarizer, an electromotive force of 2 to 2.2 volts is obtained.

The next cut, Fig. 28, serves as a representation of the Poggen-

dorff battery. There is no material difference of construction between them, and Poggendorff's battery is often called Bunsen's battery.

Sometimes the Poggendorff battery is made up without the porous cup, as in the Grenet battery described further on. The zinc and carbon are immersed in the same solution. A mixture of sulphuric acid, water, and potassium bichromate in solution forms at once the exciting and depolarizing solution. This solution acts upon the zinc disadvantageously.

For all purposes, where a powerful battery is needed and where constancy is less desirable than power in small compass, some form of the Poggendorff or bichromate couple is very available.

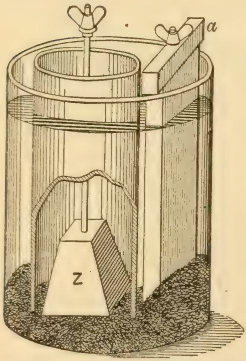


FIG. 29.—FULLER'S BATTERY.

The disadvantage of the omission of the porous cup is the dissolving of the zinc on open circuit, even if amalgamated. The combined depolarizing and exciting fluid attacks the zincs under the above circumstances. This difficulty is met by withdrawing the zincs from the solution when the battery is not in use. A great variety of this class of battery differing in mechanical details has been devised.

Modifications of Poggendorff's Battery.—Some representative batteries of the Poggendorff porous cup type are the following:

Fuller's Mercury-Bichromate Battery is shown in Fig. 29. The zinc electrode in the shape of a cone or pyramid is cast around the lower end of a copper wire, which must be insulated. It rests on its base in the bottom of the porous cup. It is in height but a fraction of the height of the cup. Mercury is poured in to the porous cup, so as to lie in contact with the zinc to keep it amalgamated. The carbon electrode is in the outer vessel. In the illustration, Fig. 29, Z indicates the zinc electrode. The porous cup receives the acid solution; the depolarizing solution is in the outer vessel. In starting, no acid need be put into the

porous cup. Enough will soon find its way in from the depolarizer to start the cell to working.

It is claimed that on an ordinary working circuit this battery can be run for six months without renewal. The internal resistance can be varied, as in any other porous cell battery, by using porous cups of varying thickness and porosity—½ ohm to 4 ohms are given as ranges of resistance of the commercial cell. It has been used in England extensively for telegraphic service.

Camacho Cascade Battery.—This battery provides for the constant renewal of the bichromate depolarizer. The cut, Fig. 30, shows a series of cells arranged on steps. The depolarizing solution is caused to flow slowly from the upper vessel into the porous cup of the upper cell. Thence by a pipe it flows from the bottom

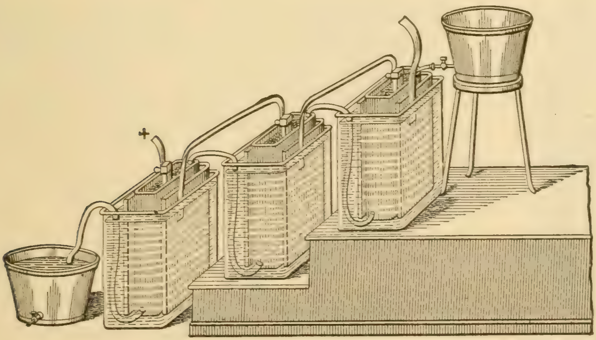


FIG. 30.—CAMACHO'S CASCADE BATTERY.

of this porous cup into the porous cup of the next lower cell. This flow goes through as many cells as desired.

Baudet Siphon Battery.—In this construction the regular porous cup construction is used. Siphons with india-rubber starting bulbs connect the outer cups of contiguous cells. The zinc plates are contained in the porous cups. The depolarizing fluid, when all the siphons are charged, will siphon from one cup to the next as long as a difference of level obtains between the liquid in the first cell and the outlet of the siphon connected to the last. Depolarizing solution is slowly admitted to the first cell, and

siphons along the row to the end one. The effective level of the outlet siphon of the last cell can be adjusted by a trap, which also keeps the siphon charged.

Radiguet Battery.—In this battery the zincs are in the porous cup. The porous cup forms one division of a double vessel, somewhat heart-shaped in contour, whose other division is glazed. The combined glazed and porous cup oscillates about a journal. When tilted in one direction, the porous division descends into the main battery cell, and the acid runs from the glazed division into the porous one. The zinc plate is fixed in position in the porous cup division. When the combined cell is tilted in the other direction, the porous cell division is withdrawn from the main battery cell, and the acid runs out of it into the glazed division.

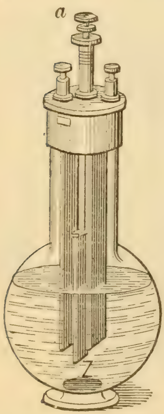


FIG. 31.—GRENET'S BATTERY.

The effect of this is that when the battery is not in use, the zinc is out of contact with acid, and the acid solution is in a separate impervious receptacle away from the depolarizing solution. The latter is in the main cell with the carbon. A single motion of the lever or handle turns the porous cup down with the zinc in it, into the depolarizing solution, and the acid simultaneously flows in and surrounds the zinc.

Other modifications of the Poggendorff cell show the dip battery principle applied to the zinc plates—the carbons being left immersed. The porous cell being only an imperfect expedient, this withdrawal of the zincs leaves the solutions to intermingle by diffusion through the pores of the porous cup, so this withdrawal of the zincs is only a partial solution of the problem.

Grenet's Battery.—In this battery, shown in Fig. 31, the zinc plate, Z, is drawn out of the solution by the handle *a* when the battery is not in use. This cell is variously constructed on the general lines shown.

Dip Batteries.—Many bichromate batteries are mounted so as to have all their plates withdrawn from the solution. All the plates are attached to a bar by which they are all raised simul-

taneously from the liquid. A sort of windlass is often mounted on a frame to effect the lifting.

Partz's Battery utilizes the different specific gravity of the liquids. The carbon lies horizontally on the bottom; the zinc, also horizontal, is suspended above it half way up the jar. It is first charged with a solution of magnesium sulphate 1:4, or ammonium chloride 1:5, or some similar salt. Five per cent to ten per cent of hydrochloric acid may be added to reduce the resistance, but it exerts local action upon the zinc. A solution of sulphuric acid and chromic acid is poured in through a glass tube, which reaches to the bottom of the vessel. This depolarizing solution of high specific gravity lies under the other solution, floating it up and covering the carbon. As the depolarizer is exhausted, more is added through the tube. This battery is credited with over 2 volts E. M. F.

Depolarizing Mixtures and Exciting Solutions in Batteries of the Poggendorff Type.—The Bunsen battery carrying out the principle of Grove, but substituting carbon for platinum, opened the possibility of new depolarizing solutions. Many such, which would attack platinum, are available for carbon. Poggendorff's substitution of chromic acid for nitric acid did away with nitrous fumes. A number of solutions for carbon-porous cup batteries have been tried, and many are of interest.

D'Arsonval (1881).—A depolarizing mixture of 1 volume nitric acid, 1 volume sulphuric acid, and 4 volumes water saturated with copper sulphate was employed by him.

Ruhmkorff (1867) and Dupré (1885).—Carrying out a suggestion due to the earlier scientist, Dupré used as polarizing solution a mixture of water 600 parts, sodium nitrate 510 parts, potassium bichromate 60 parts, and sulphuric acid 720 parts. The potassium bichromate absorbs the nitrogen oxides.

Mauri.—His depolarizer consisted of potassium chlorate 50 parts, potassium nitrate 25 parts, mercuric chloride 4 parts, iodine 5 parts.

Koosen (1873).—His depolarizer was based on the use of potassium permanganate. Two solutions are described: *a*, potassium permanganate 300 parts, sulphuric acid 100 parts; *b*, potassium permanganate 100 parts, sulphuric acid 250 parts. Water enough

to dissolve the potassium salt is used. It must be mixed with great care, the acid being added little by little to the aqueous solution of permanganate. E. M. F., 2 to 1.7 volts.

Lacombe.—Saturated solution of potassium chlorate and ferric sulphate or chloride, to which is most carefully added sulphuric acid. Potassium permanganate may be substituted for the chlorate.

Duchemin.—Picric acid solution mixed with sulphuric acid was employed as a depolarizer. It is reduced to picramic acid.

Mixture of Sulphuric and Nitric Acids.—Many depolarizing mixtures were made by mixing these two acids. The idea was to have the water combine with the sulphuric acid, so as to give a stronger nitric acid to do the depolarizing.

Potassium Bichromate Solutions.—*Formulas.*—Poggendorff.—Potassium bichromate 100 parts, water 1000 parts, sulphuric acid 50 parts.

Delaurier.—Potassium bichromate 18.4 parts, water 200 parts, sulphuric acid 42.8 parts.

Chutaux.—Potassium bichromate 100 parts, mercury bisulphate 100 parts, water 1000 parts, sulphuric acid 66° (B.) 50 parts.

Dronier's Salt.—A mixture of one-third potassium bichromate and two-thirds potassium bisulphate. It is dissolved in water just before use.

Tissandier.—Potassium bichromate 16 parts, water 100 parts, sulphuric acid 37 parts. Finely-pulverized bichromate is used. It is dissolved as far as it will in the water heated to about 100° F. The acid is then added, and the mixture shaken until all dissolves.

Kookogey.—Potassium bichromate 227 parts, boiling water 1134 parts, sulphuric acid added while water is at boiling temperature 1588 parts. It is allowed to cool, and the liquid is decanted from the crystalline residue which forms on cooling.

Trouvé's.—Water 80 parts, pulverized potassium bichromate 12 parts, concentrated sulphuric acid 36 parts; all parts by weight. The pulverized potassium bichromate is added to the water, and the acid is added slowly with constant stirring. As much as 25 parts potassium bichromate may be added to 100 parts of water.

The heating produced by the acid and water dissolves nearly all the potassium salt. Use cold.

The Daniell Battery.—The Daniell battery is the type most used probably of all primary batteries. It is of low voltage, a little over one volt, and of high resistance, several ohms in all ordinary sizes. Its great constancy and cheapness of its first cost and of its solution have made it the telegrapher's battery *par excellence.* It is being replaced by caustic potash and other batteries to some extent.

The typical cell contains a porous cup for the zinc. It is filled with water. A copper plate is placed outside the porous cup, virtually surrounding it. A pocket or receptacle for copper sulphate crystals is provided near the top of the copper plate, and is often made out of the same copper as the plate. Sometimes to start it off some salt, sodium sulphate, or zinc sulphate is added to the water.

Daniell produced the cell in 1836. Tommasi gives the invention to Becquerel in 1829. Walker in 1830 made a similar couple, using animal membrane for a diaphragm instead of unglazed porcelain for the porous cup.

The action of the cell is this: The copper sulphate dissolves. Its sulphuric acid attacks the zinc, its copper is deposited as metal on the copper plate. The fluids move by or move through the porous cup. Under the action of a current, on closed circuit, the level of the copper sulphate solution rises.

The action of this battery is subject to the defects of all porous-cup batteries. The solutions mix through the diaphragm so that the depolarizing solution comes into contact with the zinc. This is very injurious because the metallic copper precipitates on the zinc. This is done at the expense of the zinc, which is dissolved, constituting a source of expense. The dissolving of the zinc increases the specific gravity of the solution, which has to be weakened sooner than would be the case without this wasteful dissolving. The zincs have to be scraped occasionally, to free them from the copper. Both the latter features of wrong action involve extra labor.

The electromotive force varies slightly according to the salts present in the zinc compartment and with the presence or absence

of free acid. The great constancy of this battery has made it in the past a favorite for testing purposes as a standard of electromotive force. Scientific investigators have made many investigations of its reactions and determinations of its electromotive force. The latter varies from 1.160 to 1.03 volts. 1.07 volts is usually taken as the electromotive force.

The chemical reactions involved are put thus: For the vessel containing the zinc plate:

$$H_2\,SO_4 + Zn = ZnSO_4 + 2H.$$

For the vessel containing the copper plate:

$$2H + Cu\,SO_4 = H_2SO_4 + Cu.$$

The electromotive force is but slightly affected by heat. If the surface of the copper is oxidized, its voltage is slightly increased by light. Dilution of the solutions is almost without effect on its voltage. The quality of the metals in the electrodes, whether rolled or rough, crystalline or not, makes very little difference in the voltage.

The resistance of the Daniell cell is said to depend more upon the area of the copper than on that of the zinc. Amalgamation of the zincs is not favored by all investigators. Different materials for the diaphragms have been tested, and have naturally been found to have no influence on the electromotive force.

Modifications of Daniell's Battery.—These are not so numerous as might be anticipated, unless we include the gravity cells. Varley proposed to surround the porous cup with a layer of zinc oxide. This will decompose any copper sulphate which works its way through the walls of the porous jar. Copper oxide will be precipitated, and zinc sulphate will be formed. One great annoyance is the deposition of metallic copper on the porous cup's exterior. Borseul wound a spiral copper wire around the cup with a spiral plate at its lower end, the middle of the wire attached to the copper plate. The wire was supposed to catch all the copper as it precipitated.

Parelle and Veritée, in their balloon or flask battery, place the copper sulphate in a glass flask with narrow neck, as shown in Fig. 32. It is filled with water, and inverted neck downward into the porous cup. It supplies copper sulphate for a long time.

The solution in the outer jar must be weakened from time to time; otherwise, the battery takes care of the solution automatically.

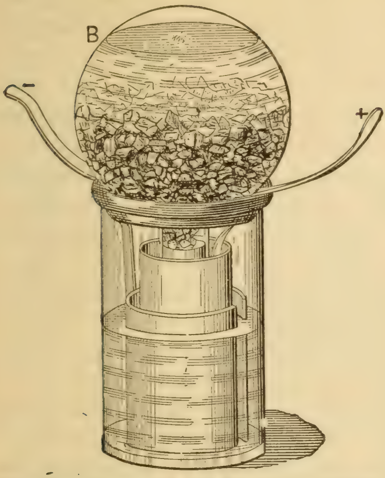


FIG. 32.—BALLOON OR FLASK BATTERY.

Trouvé's blotting-paper battery, shown in Fig. 33, contains a copper and a zinc plate marked Cu and Zn. The space between is filled with disks of blotting paper. The lower sheets of paper to one-half the total number are soaked in copper sulphate solution and allowed to dry. An insulated copper wire runs down through a central hole to the copper plate and is soldered thereto. Another wire is connected to the zinc plate. When the battery is to be used, water is poured upon the disks until it shows at the edges; they are pressed together and placed in the jar. This battery will give a small current for months.

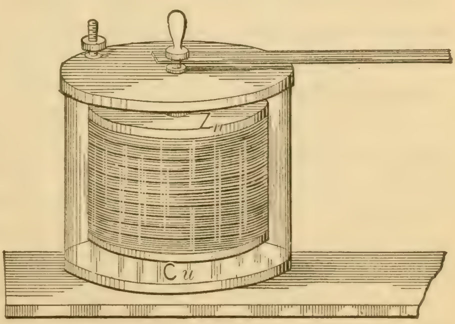


FIG. 33.—TROUVE'S BLOTTING-PAPER BATTERY.

Eisenlohr (1849) used a sodium or potassium bitartrate in the zinc division. Buff used liquid zinc amalgam. An insulated wire runs down through the solution into the mercury.

Gaiffe's cell is a combination gravity and porous cup cell. The zinc is in the shape of a cylinder, and is suspended from the edge of the jar near its top. The porous jar is glazed or treated so as to be im-

pervious for its lower half. It contains the copper plate, and a wire extends from the copper plate up over the edge of the porous cup and down to the bottom, where it is carried around the lower part of the half porous cup in a circle. Any copper sulphate in the porous jar as it works its way through descends on account of its specific gravity to the bottom of the outer jar. When the circuit is closed, this copper sulphate is the first decomposed, and the copper ring acts as an electrode. When this part of the solution is exhausted, the copper in the porous jar becomes the negative electrode. Then the cell works like a regular Daniell's battery. This construction favors the preservation of the zinc from local action or attack by the copper sulphate solution.

D'Arsonval (1881) has, by using caustic soda solution in the zinc compartment, brought up the voltage to 1.5 volts.

Reynier reached the same voltage, using a seamless bag of parchment paper for the porous cup, a 30 per cent solution of caustic soda for the zinc compartment, and sodium bisulphate or sulphuric acid in the copper sulphate solution. He used other mixtures, whose complication tends to exclude them from every day use.

Sand Type of Daniell's Battery.—Several cells have been devised in which a layer of sand replaces the porous cup. Minotto (1863) uses sand, D'Arsonval uses animal black or bone black, Coronat uses sawdust. There are other modifications.

Gravity Battery.—This term is almost restricted to one type of cell, the copper-zinc-copper sulphate couple. It is based on the exact reactions of the Daniell cell, but has no porous cup, relying entirely on the various specific gravities of the constituent liquids to keep them separated. The construction of the modern gravity battery is cheap, because the porous jar is dispensed with. The original gravity battery dates back to 1859, when it was produced by Meidinger. There is apt to be a little uncertainty about the originators of fundamental things in the world of practical science, but this inventor going back nearly fifty years has given his name to the gravity battery, and the title adheres to it still.

Meidinger's Battery (1859).—The cup was contracted in diameter at about one-third of its height, so as to form a shoulder, on

which a cylinder of zinc rested. A smaller cup rested on the bottom of the main cup, and contained the copper electrode. This cup held strong copper sulphate solution, whose high specific gravity operated to prevent it rising and attacking the zinc when on open circuit. A glass tube with a hole in its bottom was arranged to keep up the strength of the copper-sulphate solution. A flask such as shown in Fig. 32 is sometimes applied to this battery.

The next steps in the development of this cell were in the direction of simplification, and in modern cells there are often only three parts, two electrodes and the jar. A copper electrode which rests on the bottom of the jar, a zinc electrode of approximate disk shape supported in a horizontal position near the top, and the battery jar are the three parts. To charge it, the copper electrode is put into the jar, resting on its bottom, and crystals of copper sulphate are introduced to a depth of two inches or more. It is then carefully filled with water to within an inch of the top. The solution of copper sulphate is of higher specific gravity than water, and stays at the bottom more or less completely, especially if the battery is in use. But if the battery is little used and remains on open circuit, most of the time the copper sulphate solution rises and acts upon the zinc, attacking it, depositing metallic copper upon it, and impairing rapidly the condition and efficiency of the battery.

The zinc dissolves, forming zinc sulphate, whether the battery is working or not. In the first case, the zinc should and must dissolve; in the second case, when the battery is not working, the solution is due to local action and is a defect. The inevitable formation of zinc sulphate acts to increase the specific gravity of the overlying solution, and to diminish the characteristic gravity feature of the cell. Accordingly, from time to time some of the zinc sulphate solution must be withdrawn and its place supplied by water. This dilution with water and the occasional addition of copper sulphate, called in the telegrapher's vernacular "bluestone," should be all the attention the battery requires. If left much on open circuit, additional attention is called for—the occasional scraping of the zincs to free them from deposited copper.

The cut, Fig. 34, shows Lockwood's construction of the gravity

cell. A spiral wire connected to the copper plate in the bottom of the jar lies above the copper-sulphate crystals, and is designed to prevent the copper-sulphate solution rising and attacking the zinc. It acts by decomposing the solution. There are many other varieties.

Modification of the Gravity Cell.—Thomson's battery, starting with saturated solutions of both copper sulphate and zinc sulphate, has the latter underlying the former, as it is of higher specific gravity. The zinc is in the bottom, the copper near the top of the cell. Cardarelli in 1883 is credited with the same idea. Cupric chloride has been used as a substitute for the copper sulphate. On open circuit the copper is at-

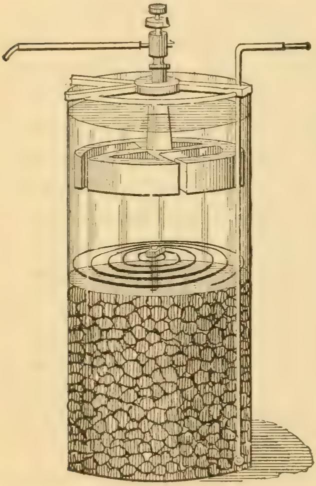


FIG. 34.—THE GRAVITY BATTERY. (Lockwood's.)

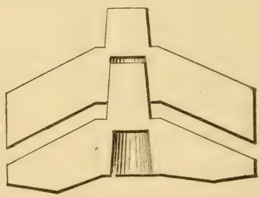


FIG. 35.—D'INFREVILLE'S WASTELESS ZINCS FOR GRAVITY BATTERIES.

tacked, reducing the cupric chloride to cuprous chloride. On closed circuit this reaction does not take place. Delaney inclosed the zinc in a paper envelope, and the copper sulphate in a strawboard box. The zinc is but little subject in this battery to local action. D'Infreville's wasteless zincs provide for the attachment of partly expended zincs to the bottom of the new one. In ordinary practice nearly half the zinc is wasted, as the plates get so corroded as to require replacing. In this system such plates are attached below the old one, their stem, which is slightly conical, being forced up into a hole in the center of the other zinc, as shown in the sectional diagram, Fig. 35. The half-dissolved

old plates are thus used up. The cut shows a partly-expended one below a new one.

Sir William Thomson's gravity battery, shown in Fig. 36, consists of a shallow tray on whose bottom rests a sheet of copper. Copper-sulphate solution covers the copper plate. Four wooden rods rest on the copper, and carry a grating of zinc contained in a parchment paper tray or box. The resistance, owing to the large surfaces and their nearness, is low compared to the ordinary Daniell or gravity battery. Thomson's battery in a

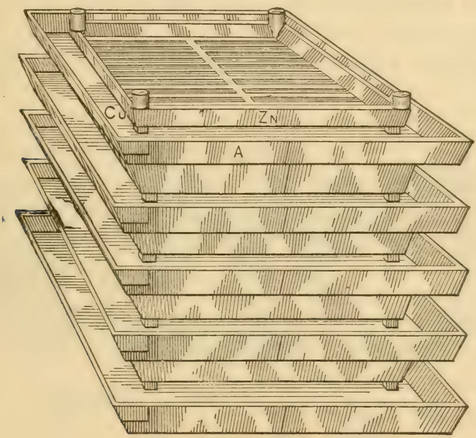


Fig. 36.—Thomson's Battery.

measure comes between the two, as the parchment paper diaphragm and the specific gravity of the copper-sulphate solution each play a part in preventing local action. The trays are piled one on top of the other.

Caustic Alkali Batteries.—Many batteries have been based on the action of caustic alkali on zinc. It dissolves the metal much as an acid does, and brings about polarization of the negative electrode unless some means are taken to overcome it. Black oxide of copper, cupric oxide, is the favorite depolarizer in this class of battery; so much so, that the name "oxide of copper battery" is often applied to the class.

Lalande and Chaperon (1881).—These inventors have done much to bring the caustic alkali-oxide of copper couple into prominence. Amalgamated zinc copper in a 30 per cent solution of caustic alkali with copper oxide as depolarizer is the combination. The alkali acts on the zinc, and the nascent hydrogen reduces the copper oxide to the metallic form. The electromotive force may be as high as 0.98 volt. With electrodes 4 inches square and 2 inches apart, the resistance is 0.25 ohm. In one form an iron battery jar is used, which forms the negative electrode, taking the place of copper. As soon as a portion of the oxide of copper becomes reduced, the latter may operate as a copper electrode to some extent.

In one form, Fig. 37, the battery jar and negative electrode are

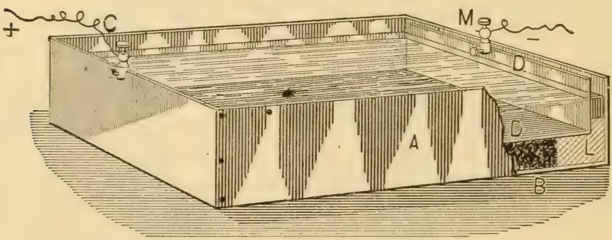


FIG. 37.—LALANDE'S TROUGH BATTERY.

represented by an iron tray, A. A layer of oxide of copper, B, is spread over its bottom. Insulating blocks, L, carry an amalgamated zinc plate, D, which rests horizontally upon them. The caustic alkali used as excitant is covered with a layer of heavy petroleum oil, to prevent the carbon dioxide of the atmosphere from acting on the caustic alkali and destroying it. M and C are the binding posts.

The Lalande and Chaperon battery does not suffer by standing on open circuit, as there is no local action. The chemical reactions are as follows:

$$Zn + 2KOH = Zn\ (KO)_2 + H.$$
$$2H + Cu\,O = H_2\,O + Cu.$$

This cell can be treated as an accumulator. By passing a reverse current through it, the elements are restored to their original state, except that the zinc electrolyzed is of such spongy consistency that it can only be used by amalgamation with a sufficient quantity of mercury.

Modifications of the Lalande and Chaperon Battery.—The Edison-Lalande battery has been quite extensively introduced. It is distinguished from the original Lalande and Chaperon battery by the use of consolidated plates of copper oxide instead of the granular substance. The oxide is mixed with 5 to 10 per cent of magnesium chloride, molded, and ignited to red heat. In this way a hard cake or agglomerate results. The ordinary type of cylindrical battery jar is used; the plates are vertical. The copper-oxide plates are held in a brass frame, which forms the negative electrode. As the copper oxide becomes reduced on the surface, it may be regarded as forming a part of the negative plate. Caustic soda is used as the alkali. Heavy petroleum oil is kept on the surface of the solution, to exclude the air. The electromotive force is about 0.7 volt, and the internal resistance is 0.03 ohm. The low resistance is a good feature, compensating in some measure for the low voltage, which falls still lower on open-circuit work. A 2¼-pound plate of oxide of copper charges a 300-ampere-hour cell, or about 1/5 horse-power hour.

Ammonium-Chloride Batteries.—For open-circuit work zinc-carbon ammonium chloride batteries have had considerable vogue. Depolarizing is requisite unless the surface of the carbon electrodes is very large compared to that of the zinc. The following are typical cells of this type:

Leclanché Battery (1868).—There are two types of Leclanché battery, one the porous cup cell, the other the agglomerate cell. In the first, shown in Figs. 38 and 39, the zinc is in the outer vessel in a solution of ammonium chloride, the carbon is in a porous jar which is filled with a mixture of pulverized carbon and black oxide of manganese, preferably needle-form or crystalline. The porous cup should be of good quality and porous. The electromotive force is 1.48 volts. The top of the porous cup is now generally sealed with pitch or some equivalent. The porous cup does not usually last more than two years. One part of zinc

dissolved should reduce two parts of manganese dioxide and should exhaust one part of ammonium chloride. Strong ammonium chloride is advisable as it is a better solvent for the zinc oxychlorides formed. In the agglomerate battery there is no porous cup but the depolarizer is in two cakes which are held against the carbon plate by rubber bands. The cakes consist of 40 parts binoxide of manganese, 52 parts of carbon, 5 of gum lac, and 3 of potassium bisulphate, compressed at a pressure of

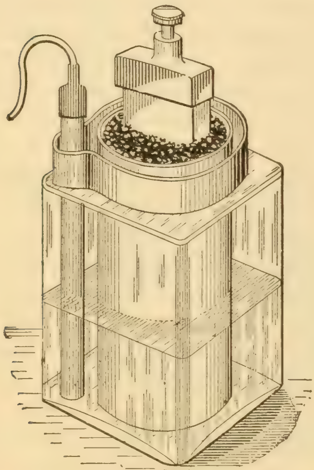


FIG. 38.—LECLANCHE BATTERY.

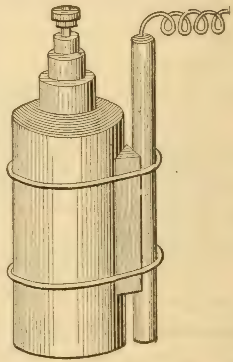


FIG. 39.—ELEMENTS OF A LECLANCHE BATTERY.

300 atmospheres at the temperature of boiling water. It is important to use ammonium chloride of good quality, as the impurities liable to occur in commercial sal-ammoniac tend to increase the resistance. The reaction is expressed thus:

$$2NH_4Cl + 2MnO_2 + Zn = ZnCl_2 + 2NH_3 + H_2O + Mn_2O_3.$$

But there are other reactions which may occur. Thus, ammonium nitrate may be formed; at the beginning of the reaction a mixture of hydrogen and carbon dioxide and nitrogen is liberated; after a long period of action, hydrogen alone is liberated.

Various modifications have been devised. In the Barbièr cell

the agglomerate is molded into a hollow cylinder within which the zinc rod is placed. In another a cylindrical plate of zinc surrounds the agglomerate cylinder in addition to the interior rod of zinc. In these the agglomerate acts as the negative electrode; there is no carbon electrode employed. In the Gaiffe cells the carbon and binoxide of manganese are placed in strata or layers. In one form Gaiffe uses a porous cup, in the other the carbon is a hollow cylinder and acts as porous cup and negative electrode.

The resistance of commercial Leclanché cells varies from 4 to 10 ohms.

Dry Batteries.—A dry battery is one which has its electrolyte disseminated through some solid material through which it can diffuse itself. Plaster of Paris and gelatinous compounds have been used for the solid part. The usual construction is on the basis of the plaster of Paris combination.

The outer cup is made of zinc, and acts as the positive electrode. Over it is slipped a strawboard tube. The object is to prevent the zinc of two batteries from touching each other so as to establish a wrong connection. The negative electrode is a plate of carbon. This is placed in the center of the zinc, and is so supported as not to touch it in any place. Carbon and zinc both carry binding posts. The filling varies. The following is used in the Burnley cell:

A wooden plunger or template, somewhat larger than the carbon, is inserted, and the following mixture introduced: Ammonium chloride, zinc chloride, 1 part of each, plaster of Paris, 3 parts, flour 0.87 part, water 2 parts. After this has set a little, the wooden template is withdrawn, the carbon is inserted in the cavity left by its withdrawal, and the space left unfilled is filled with the following mixture: Ammonium chloride, zinc chloride, manganese binoxide, granulated carbon, flour, 1 part of each, plaster 3 parts, water 2 parts. The electromotive force of this cell is 1.4 volts, its resistance 0.3 ohm.

The Gassner dry cell has as negative a cylinder made of a mixture of carbon and manganese dioxide. The filling composition is as follows: Zinc oxide, ammonium chloride, and zinc chloride, 1 part each, plaster of Paris 3 parts, water 2 parts.

For the Meserole dry battery, there are mixed the following: Graphite, slaked lime, arsenious acid, and glucose or dextrine, 1 part each, carbon and manganese binoxide, 3 parts each. The mixture is finely pulverized and rubbed up in a saturated solution of ammonium chloride and sodium chloride (common salt) with one-tenth its volume of a solution of mercuric chloride and an equal volume of hydrochloric acid. These constituents are intimately mixed and poured into the zinc cup.

Dry batteries are sealed with pitch. A hole is sometimes left for the escape of gas.

Arrangements of Batteries.—Primary batteries may be arranged in series, in parallel, or in series multiple or multiple series. The best arrangement from the point of view of economy is to keep down the resistance of the battery by putting as many in parallel as is consistent with the voltage required. Each cell is taken as of a certain voltage and resistance. Although these factors change considerably, yet some basis must be taken for calculation, and only an approximation is attainable in practice.

Assume a battery of twelve cells arranged in series, and assume that each one has a resistance of 2 ohms and an electromotive force of 1.5 volts. The resistance of the external circuit is 25 ohms. What current would be produced? The total electromotive force of the battery is $12 \times 1.5 = 18$ volts. The resistance of the battery, 24 ohms, added to that of the outer circuit, 25, is $24 + 25 = 49$. By Ohm's law the current $= \frac{E}{R} = \frac{18}{49} = 0.37$ ampere.

Assuming the same battery arranged in parallel on the same external circuit. What current would be produced? The electromotive force of two, twelve, or any other number of cells in parallel is equal to that of a single cell. The resistance of the battery is found by dividing the resistance of one cell by the number in parallel. The electromotive force of the battery, therefore, is that of a single cell, or 1.5 volts; the resistance is the quotient of a single cell's resistance divided by the number of cells, or $\frac{2}{12} = \frac{1}{6}$ ohm. The total resistance of the circuit is

$25 + 1/6 = 25\,1/6$ or $\frac{151}{6}$ ohms. The electromotive force is 1.5 or 3/2 volt. The current by Ohm's law is $\frac{3}{2} \div \frac{151}{6} = \frac{18}{302} =$ 0.06 ampere nearly.

Thus one arrangement of the same battery gives over six times the current given by the other.

Assume that the same battery is connected on a circuit of 1/5 ohm. With the cells in series we have an electromotive force of 18 volts, an internal resistance of 24 ohms, an external resistance of 1/5 ohm, a total resistance of $24\,1/5$ or $\frac{121}{5}$ ohms and a current of $18 \div \frac{121}{5} = \frac{90}{121}$ or 0.75 ampere.

Assume now that the battery is connected in parallel. The

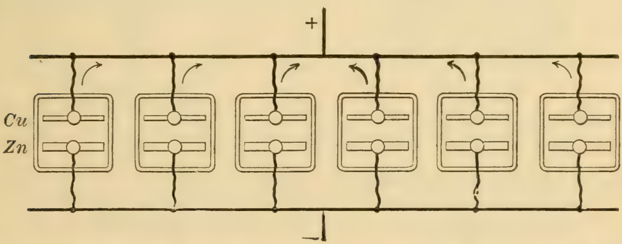


FIG. 40.—BATTERY CONNECTED IN PARALLEL OR MULTIPLE ARC.

internal resistance is 1/6 ohm, the total resistance is $1/5 + 1/6 = \frac{11}{30}$ ohm. The electromotive force is 1.5 or 3/2 volt; the current is $\frac{3}{2} \div \frac{11}{30} = \frac{90}{22} = 4.09$ amperes.

A low external resistance increases the current. An internal resistance equal to the external resistance gives the greatest current which the battery can produce through such external resistance. These are the principal laws of battery connection.

Batteries may be arranged in other ways. Assume the battery to be arranged three in parallel and four in series. Its resistance varying directly with the cells in series and inversely with the

cells in parallel, the resistance of the combination is given by multiplying the resistance of a single cell by 4/3; $2 \times 4/3 = 8/3$ ohms, the resistance of the battery thus arranged.

The electromotive force is unaffected by the number of cells in parallel but varies directly with the number in series. The

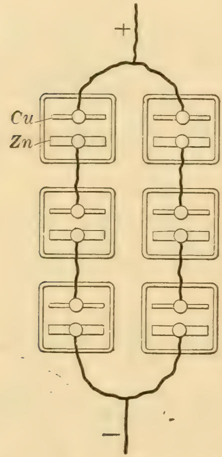


FIG. 41.—BATTERY ARRANGED THREE IN SERIES AND TWO IN PARALLEL.

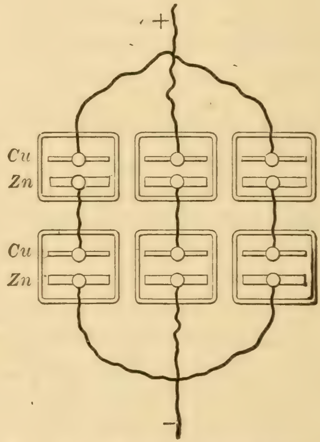


FIG. 42.—BATTERY ARRANGED TWO IN SERIES AND THREE IN PARALLEL.

electromotive force is therefore equal to $3 \times 1.5 = 4.5$ or 9/2 volts; and the current by Ohm's law is $\frac{9}{2} \div \frac{8}{3} = \frac{27}{16} = 1.69$ amperes.

In late years, as primary batteries are being supplanted by other generators, battery calculations are of less importance than formerly. They should be understood and practised as they give an excellent insight into Ohm's law.

In Figs. 40, 41 and 42 three different arrangements of six battery cells are shown.

CHAPTER VII.

STORAGE BATTERIES.

The Primary Battery.—A primary battery, as has been explained, consists essentially of two plates or electrodes and of an electrolyte or fluid, which attacks one of the plates. As hydrogen gas accumulates on the unattacked plate, some highly-oxidized substance is often used to provide oxygen. This oxygen combines with the hydrogen and forms water.

Only one plate is attacked, because the material of the plates differs. One is made of a metal soluble in or attacked by the electrolyte; the other is of a material on which the electrolyte has no action.

When a primary battery produces a current, three things happen. The soluble plate, practically always zinc, dissolves. The electrolyte becomes exhausted as it dissolves the zinc. The depolarizer becomes exhausted by giving up its oxygen to the hydrogen and forming water. To put the battery into working order, a new zinc plate, new electrolyte, and new depolarizer must be supplied, and the old exhausted solutions and depolarizer are thrown away. This involves a great deal of labor, which is expensive, and requires new zinc and chemicals, which are also expensive.

Action of a Storage Battery.—A typical storage battery includes the elements cited above. There is an electrolyte, two plates, and a depolarizer. The production of current oxidizes and may dissolve the material of one plate, and the electrolyte is exhausted in the process. The hydrogen, which seeks the inactive plate, finds there a depolarizer, and this is gradually decomposed and reduced as it supplies oxygen to the hydrogen. After a time the battery is exhausted, and no longer in a condition to produce current.

Regeneration.—To regenerate it, neither labor nor supplies are needed. A current of electricity of opposite direction to that which the battery originally produced is passed through it. This reproduces by electrolytic reduction the attacked electrode on one plate; it forms upon the other plate the depolarizer, also by electrolysis. As these two actions take place, the electrolyte is restored to its original strength. After a sufficient time of "charging," as this process is termed, the battery is restored to its original condition. The charging current is stopped, and the battery is ready for producing current again.

In place of labor, chemicals, and new zinc plates we have electric energy, in the shape of a current with electromotive force. The electric energy is produced at a cost far less than the equivalent in primary battery supplies. The storage battery also has an exceedingly low resistance. These are the causes of its economy, and its economy has made it available for the heaviest service.

The accumulator, storage battery, or secondary battery as it is indifferently called, is a battery which, when polarized or rendered inactive by production of a current for a time, can be restored to its original condition by passing a current through it in the reverse direction.

Grove's Gas Battery.—Grove's gas battery, which dates back to 1829, is the first prominent storage battery. Plates of platinum are contained in tubes airtight at the top and open at the bottom. The lower ends are immersed in vessels of dilute sulphuric acid, each tube being filled with acid before immersion, and kept full until immersion. Air pressure then maintains the column of water in each tube. The platinum plates are connected as shown in the cut, Fig. 43. M M are the cups of dilute acid. P and N indicate the main leads. A charging current entering at A and leaving at B charges the tubes A, A′, etc., with oxygen gas, and those marked B, B′, etc., with hydrogen gas, H. The latter has almost exactly double the volume of the oxygen, O, as is indicated by the level of the letters H and O in the cut. By this operation the platinum plates are caused to emerge from the solution. When pretty well exposed, each surrounded by its own gas, oxygen and hydrogen respectively, if

the terminals are disconnected from the charging circuit, a current in the reverse direction can be taken from the battery by connecting the plates with a wire just as if they were ordinary battery plates. The hydrogen and oxygen disappear as current is taken, and the plates become covered with the solution again. The platinum plate in the oxygen tube represents the copper or carbon plate in an ordinary battery. The hydrogen in the other tube represents the zinc. The platinum plate plays the *rôle* of conducting electrode.

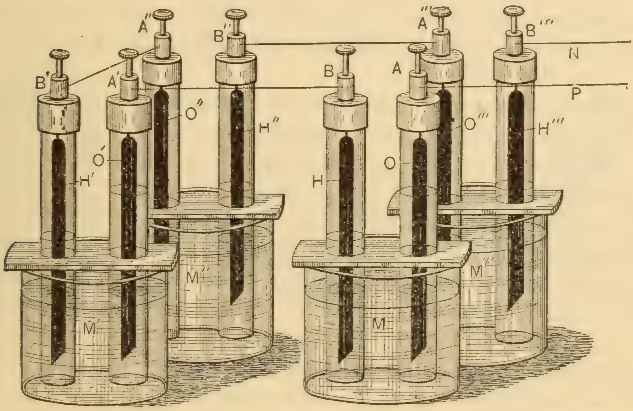


FIG. 43.—GROVE'S GAS BATTERY.

Sometimes the battery was charged by introducing hydrogen and oxygen gases directly into the tubes.

Under favorable circumstances each couple gives 0.843 volt electromotive force.

Even before Grove's date, in 1803, Ritter built up piles with disks of identical metal throughout separated by cloth moistened with dilute sulphuric acid. A current passed through this, caused hydrogen gas to accumulate on one face of the disks and oxygen on the other. On disconnecting it from the source of current, a reverse current was given by it when its terminals were connected.

Much work of scientific interest has been done in this line of research. Palladium and carbon have each been substituted for platinum, and the effect of a porous diaphragm separating the plates has been tried.

The gas batteries are only of scientific interest, they have no practical value. The following have been given as the requirements of a practical storage battery.

Requirements of a Storage Battery.—It must absorb the greatest quantity of "electric energy" with the smallest volume, and above all with the smallest weight. The charge should be retained for long periods without loss. The battery should make a good return; its efficiency should be high. The battery should give a constant current, without intermittence, and should be subject to regulation.

Function.—Before going on with the subject, the function of storage batteries may again be referred to. They do not directly store electricity, except a little which is incidental only and not taken into account. Their action is simply to provide a battery which when exhausted can be brought back into its original condition by electrolysis. It is as if a carbon zinc sulphuric acid couple were so constructed that when the acid was expended and the zinc dissolved, we could rejuvenate the cell or reproduce zinc and electrolyte by passing a current of electricity through the battery. The current would have to go in the opposite direction to the natural current of the battery.

As a matter of convenience, we speak of the amount of electrical energy a battery can store up. Properly, it is potential chemical energy which is stored up; the other expression is practically correct, and can be used to express the result. As long as the action of the battery is understood, the convenient expression can be used without implying a misunderstanding of the theory.

Planté's Battery.—In 1859 or 1860 Gaston Planté first solved the problem. The importance of his work is shown by the use of the Planté principle in batteries of the present day. Lead-plate electrodes are still the most successful ones for storage batteries, and to Planté is credited their first use in this *rôle*.

His original battery was made of two sheets of lead. They

are laid flat, one above the other, with a non-conducting substance or strips between them. Canvas was one of the first separators used; later, India-rubber strips were employed. The plates have each a strip of its own substance projecting from a corner. The two plates with intervening insulating strips or equivalent are then rolled up into a spiral. The process and its result are shown in Fig. 44. The plates must not touch, or the couple will be short-circuited and inactive. The plates are immersed in a 10 per cent solution of sulphuric acid.

Forming.—The next process is the forming of the plates. The

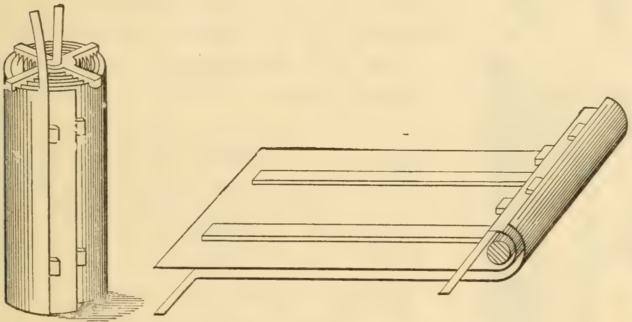


FIG. 44.—PLANTE'S STORAGE BATTERY PLATES.

object is to cover one plate with as thick a coating of lead peroxide as possible, and to make the surface of the other plate as spongy as possible. The new battery is first subjected to the forming process. One lead plate is connected to one terminal of a circuit and the other to the other. One plate of lead collects oxygen and is oxidized. The other evolves hydrogen gas. After this is kept up for a while, the charging circuit is removed and the plates are connected by a wire. A current in the opposite direction to that of the charging current is now produced. When no more current is generated, the charging circuit is reconnected, but in the reverse of the former direction. The process goes on as before, except that this time the other plate is oxidized. Then the battery is discharged, and is re-

charged in the original direction. This sequence of processes may be kept up several months. It is of importance, before connecting the reversed charging current, to have the battery almost completely discharged. Sometimes the solution is heated, to accelerate the forming process.

To assist the forming process, the surface of the plates may be mechanically roughened, or may be corroded with dilute nitric acid. When formed, one plate is reddish in color because it is covered with binoxide of lead, PbO_2. This plate is called the positive plate in storage battery nomenclature, although it corresponds to the carbon plate in primary batteries. Many modifications of the battery have been made.

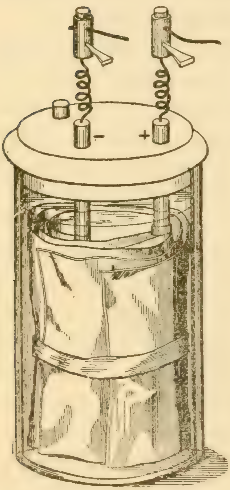


Fig. 45.—Faure's Storage Battery.

The first electromotive force given by a Planté couple is 2.53 volts. This soon falls to 2.1 volts, and for two-thirds of the discharge it remains at 2.02 volts.

The resistance of a cell with 775 square inches of total lead surface with plates 0.2 inch apart varies from 0.04 to 0.06 ohm, according to the condition of the plates.

Storage Capacity.—A Planté couple will give 36,300 coulombs per kilogramme of lead for its whole discharge. At 2 volts this gives 72,720 volt-coulombs, or about 95 horse-power seconds, or about 0.03 horse-power-hour of energy. It returns 89 to 90 per cent of the coulombs used in charging it. As much as 19 grammes of copper per 1,000 grammes of lead electrodes has been deposited by it on a single charge.

By connecting 800 elements in series, M. Planté obtained sparks 2 inches long.

Faure's Battery.—In 1881 Faure used red oxide of lead in combination with lead plates. The plates were coated with a paste of red lead and acid. Parchment paper and felt were placed over the layer, and the plates were rolled up with intervening strips of India rubber, as in Planté's original cell. It is shown

in Fig. 45. This construction was defective from several aspects. The felt increased the resistance, might tear and short-circuit the plates, and the lead oxide had very poor adherence.

The Faure-Sellon-Volckmar Battery.—In this battery the felt and parchment paper were not used. The plates were pierced with holes, and red lead was packed into the holes in the positive plate and litharge into those in the negative plate. In charging, the litharge is reduced to spongy lead, the red lead is oxidized to brown oxide ($Pb\,O_2$).

In this battery straight plates or grids were substituted for the spiral rolled plates of the Planté and Faure cells. The weight of a 30-kilogramme cell (66 pounds) was thus divided:

Lead electrodes and oxides......	16.8 kilos.	37 pounds
Acid	6.5 kilos.	14 pounds
Cell	6.0 kilos.	13 pounds
	29.3 kilos.	64 pounds

The formation of the cell took about 100 hours. An electromotive force of about 2 volts was produced on its discharge.

Chemical Action.—The following reactions are ascribed to the storage cell with lead plates, by Gladstone and Tribe. First is the discharge or action of the battery:

$$\overset{-}{Pb} + 2H_2\,SO_4 + \overset{+}{Pb\,O_2} = \overset{-}{Pb\,SO_4} + 2H_2O + \overset{+}{Pb\,SO_4}.$$

The — and + signs above the line indicate the positive and negative electrodes. For the charge the layers of lead sulphate, $Pb\,SO_4$, have to be brought back to their original condition, one to metallic lead, Pb, the other to peroxide of $Pb\,O_2$.

$$+ \text{ Electrode } Pb\,SO_4 + O + H_2O = \overset{+}{Pb\,O_2} + H_2\,SO_4.$$

$$- \text{ Electrode } Pb\,SO_4 + 2H = \overline{Pb} + H_2\,SO_4.$$

There are other theories. The above is so simple that it will answer in the existing circumstances as at least a general explanation of the reactions.

A great number of variations in construction of storage batteries have been tried. It is astonishing how small a departure from the Planté and Faure-Sellon-Volckmar cells has been made

by modern constructors. The Planté plate slightly modified, is still in use in modern batteries. But Planté did much more than is spoken of here. He constructed batteries with flat parallel plates separated by insulating buttons, not confining himself to spiral plates as in his first efforts.

Resistance.—The increasing of the plate area in storage batteries effected an improvement in the direction of efficiency of the entire circuit. It lowered the resistance. The nature of the electrolyte in Planté's battery added to this effect, as the conductivity of dilute sulphuric acid is high. All storage batteries are constructed with a view of lowering resistance, and for industrial purposes are made very large. The effect of this is that exceedingly large currents can be taken from them.

To accelerate the charging process, or to give the plates a better and deeper active area, subdivision of the plate surface is resorted to.

Gould Storage Battery.—In this battery the Planté system of direct formation of a solid lead plate is adhered to, but to increase the surface the lead plate is mechanically treated.

A very dense rolled lead of chemical purity is used for the plates. This is cut into blanks of the desired size of the plate. The blanks are placed in steel frames, and caused to move back and forth in reciprocating motion between two rollers. These rollers consist of revolving shafts on which are strung steel disks, separated from one another by alternate washers, also strung on the shaft. The composite rollers press upon both surfaces of the lead, and form it into ridges and grooves. The shape and spacing of the steel disks determine the shape of ridges and grooves.

The action is not simply cutting. The lead yields to the pressure, and by "cold flowing" rises up into ridges between the forming disks. No lead is removed, it is simply pressed, burnished, and spun into shape. The length of path traversed by the rollers can be varied. On the small plates it is a little short of the length of the plate. This leaves an unspun portion at each end, which portion anchors the ribs in place. On large plates, by rolling the plate in two or more sections, a number of transverse unspun portions are left, and sometimes vertical

strengthening bars are left untreated. A plate may be divided thus into any desired number of areas of ribbed surface, separated by solid bars or bridges to stiffen the plate and anchor the ribs.

This process increases the surface of the lead from ten to twenty fold, yet gives a one-piece plate. From 200 to 400 square inches of surface per pound of lead are produced; 250 square inches of surface per ampere of normal current is given. The ribs vary from 0.005 to 0.040 inch thick, according to the work they have to perform. The negative plate generally has ribs 0.012 inch thick. The grooves vary from 0.005 to 0.024 inch wide.

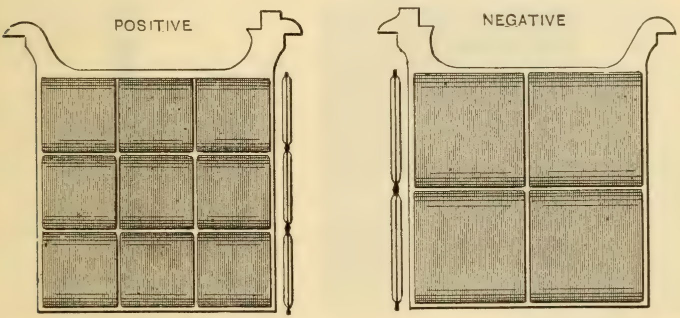


FIG. 46.—POSITIVE AND NEGATIVE PLATES OF GOULD'S STORAGE BATTERY.

When the plates are formed, which is done electro-chemically, the grooves become charged with material, lead peroxide or reduced lead, whose presence reinforces the ribs.

The great area of active surface operates to give the battery a very low resistance, so that a very heavy current can be taken from it.

In the cut, Fig. 46, a positive and negative Gould plate are shown.

Helios-Upton Battery, Philadelphia.—The plates in this battery are made of chemically-pure lead. They are sawed transversely part through, so as to form them into narrow horizontal grooves very close together. They are formed by electro-chemical process. The positive and negative plates for each cell, con-

stituting an element, are insulated or kept apart by rubber separators, and are bound together, so as to form a unit, which can be readily handled and lifted about by grasping both end bars at once. The manufacturers prescribe as a minimum discharge limit 1.5 volt, which is lower than that normally allowed in general practice. Portable batteries are shipped ready for use with electrolyte in the cell. An efficiency of 93 per cent and a current of 5 amperes per pound of element in continuous commercial operation is claimed for it. A two-year guarantee is

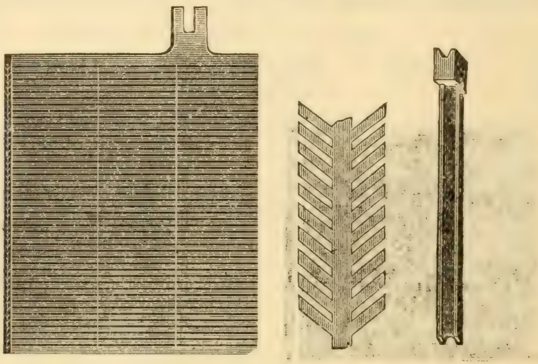


FIG. 47.—FRONT VIEW AND CROSS-SECTION OF PLATE OF AMERICAN STORAGE BATTERY WITH SEPARATOR.

given, provided the battery is charged and discharged at normal ratings.

American Storage Battery.—The storarge battery made by the American Battery Company, of Chicago, is illustrated in one of its distinctive varieties in the cuts. The lead plates are horizontally grooved as shown, with the grooves looking upward. This construction prevents material dropping from them to the bottom of the cell. Insulating strips are placed between the plates. The strips are notched at the ends, and three are placed between each two plates. India-rubber bands are sprung around the plates, passing through the grooves on the ends of the insulating strips. The bundle of plates can be taken in and out

of the cells without danger of injuring the plates in any way. The plates are made of pure lead, and are electro-chemically formed. The battery is designed to be very substantial.

The cut, Fig. 47, shows on the left the front view of a plate whose cross section is shown in the center figure. On the left is a separator. The next cut, Fig. 48, shows the element complete, with the separators in place and all bound firmly together by bands of insulating material. India rubber is the material used.

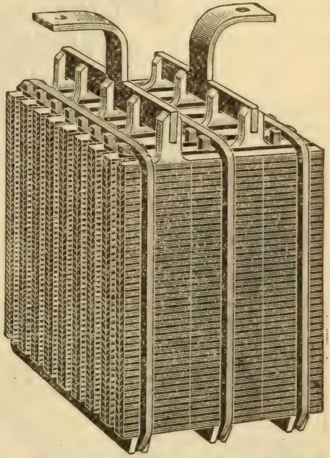


FIG. 48.—SET OF ELEMENTS OF AN AMERICAN STORAGE BATTERY CELL.

Crompton-Howell Battery.—In this battery of English manufacture, a porous or honeycombed lead plate is used. Such plates may be made by mixing with lead a quantity of fragments of metal attacked by sulphuric acid. Iron turnings might thus be used. The lead melted and mixed with iron borings would then be cast in molds. On treatment with acid the iron would dissolve and leave the lead full of small openings. The plates made on these lines are formed by the charge and discharge method. One size of plate is 9 x 9 inches and ¼ inch thick. A cell with 61 plates maintains a 1,000-ampere current for 30 minutes before the potential falls much below the normal.

Pasted Plates.—The use of oxide of lead mixed with sulphuric acid to a paste, and held on the smooth surface of a lead plate by parchment or other attachment, proved a failure in the Faure battery. Pasted plates, as they are called, are made with perforations or equivalents in the lead plates, for the purpose of retaining the oxide. Apertures may be dovetailed in cross-section, so as to retain more firmly the lead oxide which is pressed into them.

E. P. S. Battery.—This is an English battery made by the

Electric Power Storage Company, the initials of whose title give it its designation. One of its varieties is shown in the cut, Fig. 49. The plates or grids are cast full of holes, smaller in the center than on the two surfaces, so that the section of the hole represents two dovetails put together. The holes in the positive plate are filled with a mixture of red lead, Pb_3O_4, and dilute sulphuric acid. This oxide is the next to binoxide, PbO_2. The latter is the characteristic oxide of the positive plate. The holes in the negative plate are filled with litharge, PbO, made into a paste with sulphuric acid or with solution of magnesium sulphate.

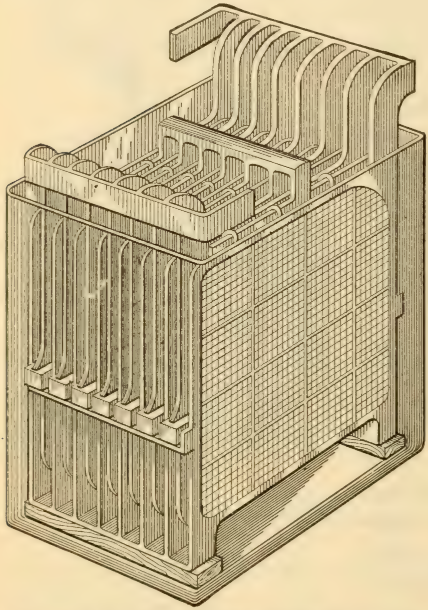


FIG. 49.—E. P. S. STORAGE BATTERY; L TYPE.

The forming seems like an intensive process when contrasted with the slow Planté forming. A strong current of 48 hours' duration forms the positive plate, and half the duration serves for the negative plate. The plates are soaked in dilute sulphuric acid before forming. When set up in the cells they are separated by glass rods. The plates have downwardly-extending prolongations forming feet on which they rest on strips of wood or equivalent in the bottom of the cell.

Chloride Battery.—This battery is made by the Electric Storage Battery Company, of Philadelphia. Lead is melted and blown into a fine spray, which cools and falls in fine shot. It is dissolved in nitric acid, and precipitated as lead chloride, $PbCl_2$. The lead chloride is melted, after drying, with zinc chloride,

and is cast into tablets. These are ¾ inch square and from ¼ to 5-16 inch thick. They are supposed to coincide in thickness with the plates. The tablets are arranged in a mold 0.2 inch apart, and held there by pins. Lead is melted and forced in under a pressure of 75 pounds to the square inch.

The metallic lead solidifies as it cools, and holds the tablets of lead chloride firmly in position. When cool, the plates represent lead grids or gratings with the openings filled with the solid mixture of lead chloride and zinc chloride. The plates are now placed in a tank alternating with zinc plates, the plates being in contact with each other. A solution of zinc chloride, $ZnCl_2$, is contained in the tanks. Galvanic action is set up; the metallic zinc is attacked, hydrogen goes to the lead plates and reduces the lead chloride to metallic lead. The hydrogen combines with the chlorine of the lead chloride and forms hydrochloric acid, so that the lead chloride is a depolarizer for this action. The zinc chloride dissolves.

Thus there is eventually produced a lead grid whose openings are filled with spongy lead. A thorough washing removes all soluble salts, and the plates are now ready for forming. The great area of surface due to the spongy lead, and its firm retention in the openings, favor the production of a plate deeply attacked in use and yet strong and durable, which are desirable features. This type of plate is especially adapted for the positive plate, as the spongy lead is in an excellent condition for oxidation and formation of lead binoxide.

The action on the plugs of mixed chlorides is two-fold. The lead chloride is reduced by the galvanic action to the metallic state, and the zinc chloride dissolves out. The object of the zinc chloride is to supply the element of porosity. As it dissolves it exposes the lead chloride in the interior of the tablets to galvanic action, so that it is reduced. The plates, when the tablets are reduced, are formed by the regular process.

Constant efforts are made to improve the storage battery, either as regards cost or efficiency. As a negative plate the following construction has been tried. A lead grid has its openings filled with litharge made into a paste with sulphuric acid. Over each face of the grid a perforated plate of lead is soldered. This

operates to pocket the litharge. In forming the litharge is reduced to metallic lead of the spongy type with large active area. The perforations in the inclosing lead plates give the electrolyte free access to it. An antimony alloy, lead 95 per cent, antimony 5 per cent or thereabouts, has been used for the positive plate, with circular holes in it, 25/32 inch in diameter, set diagonally to each other. Corrugated lead ribbons 7/16 inch wide, which is the thickness of the plate, are rolled into close spirals and are forced into the apertures in the plates. A current of 30 hours' duration is required to form these plates.

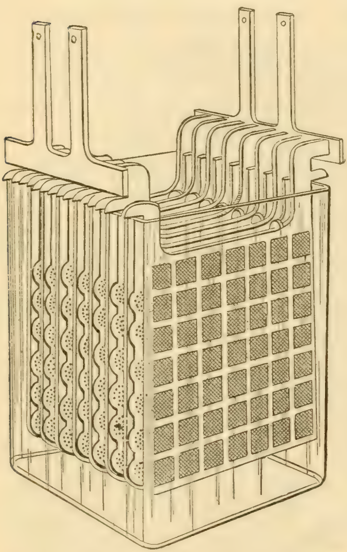


FIG. 50.—E. S. B. STORAGE BATTERY WITH ELEMENTS CARRIED ON WALLS OF TROUGH.

In the battery cell the plates are separated by cherry wood partitions, or glass rods are used as in the English E. P. S. cell. Grooves running vertically are made on the surface of the plates, to facilitate the escape of hydrogen and oxygen gas in the charging process.

Tudor Battery.—The characteristic of this battery is the treatment by charging or forming process of the plates as a preliminary operation before applying lead-oxide paste. The plates are grooved transversely with grooves of semicircular cross section. After the plates have had lead binoxide, Pb O_2, formed upon them, they are pasted with lead oxides in the regular way, and are then rolled.

Sometimes two types of plates are used in one battery. The Planté type is very available for positive plates. The Tudor type is sometimes used for this service with chloride type negatives.

Suspended Plates.—The cut, Fig. 50, shows how the plates of one of the batteries of this company are suspended in the cell.

Projections from the shoulders of the plates rest on the upper edge of the cell. In Figs. 51 and 52 another system used by the same company is shown. Two heavy plates of glass rest in a vertical position on supports in the bottom of the cell, and on these the plates rest. These cuts also show the use of glass supports or insulating feet for the cell, and the connection of the plates by bus-bars of lead.

Other Types of Pasted Plates.—It is impossible to give any-

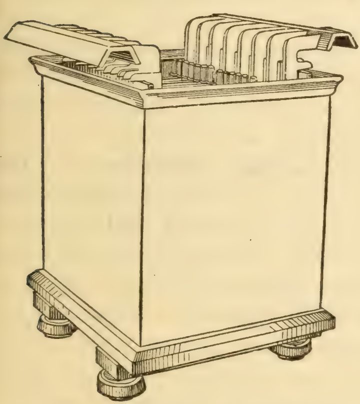


FIG. 51.—STORAGE BATTERY WITH BUS-BARS, AND ELEMENTS CARRIED ON GLASS PLATES.

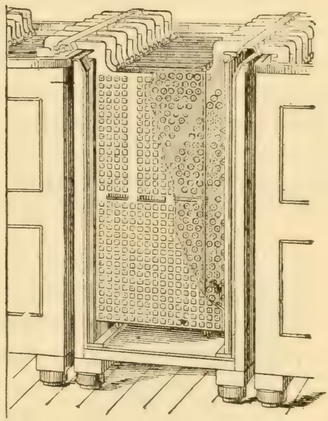


FIG. 52.—INTERIOR OF STORAGE BATTERY WITH BUS-BARS AND ELEMENTS CARRIED ON GLASS PLATES.

thing approaching a complete presentation of the many variations of pasted and compound plates. As an example of other methods of making such plates, Figs. 53 and 54 are given. Fig. 53 shows a section of a plate with apertures adapted to retain the paste introduced. The edges of the openings were burnished or rolled down after the paste was introduced, thus binding it in place. Fig. 54 shows a plate made by casting lead around little cylinders of porous lead oxide made up beforehand.

Copper Storage Batteries.—In this type of battery the positive plate is peroxidized lead, as in the lead-plate batteries; the

negative is copper-plated lead. The liquid is an acid solution of copper sulphate. The electromotive force of a cell is 1.68 volts. In another form amalgamated lead was used. The mercury dissolved during the charging process, and left the lead in a better

FIG. 53.—SECTION OF DRAKE & GORHAM'S STORAGE BATTERY PLATE.

condition for peroxidizing. An advantage claimed for copper sulphate storage batteries was that the color of the solutions showed their condition. When it was colorless, they were fully charged; when discharged, the solution was blue.

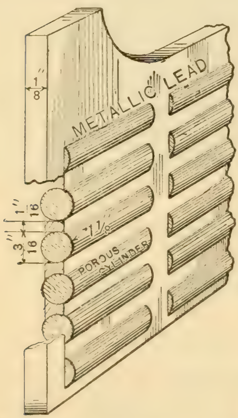


FIG. 54.—RECKENZAUN'S STORAGE BATTERY PLATE.

Zinc Acid Storage Batteries.—In this type the positive plate is peroxidized lead; the negative is zinc-plated lead, the solution is an acid solution of zinc sulphate. The electromotive force is 2.3 volts.

Waddell-Entz Battery.—This is a copper oxide zinc caustic potash couple. Some years ago it was used on one of the street railroads in New York, but never acquired very extensive use. The operation of discharging is that of the Lalande-Chaperon battery. Oxide of copper, CuO, coating the positive plate, is reduced to metallic copper, and zinc is dissolved from the negative plate. On charging, the positive plate is oxidized to copper oxide. The alkaline solution of zinc is electrolyzed, and metallic zinc is plated or deposited on the negative plate. Like the Lalande-Chaperon cell its electromotive force is low, being only 0.7 volt; about one-third that of the ordinary Planté type of battery.

Edison's Storage Battery.—This battery was originally de-

signed to meet the requirements involved in operating an electric automobile. The service is a very severe one, and greatly reduces the efficiency of the lead plate battery, because the current is sometimes used at such high rates. The lead plates are liable to suffer greatly at these high discharge rates and in the mechanical disturbance to which they are subjected. The wear on the battery is excessive. The lead plates are exceedingly heavy, which is a disadvantage.

In designing a battery to compete with the lead plate combination, no comparison can be instituted with the efficiency or durability of the carefully treated station battery. In an electric power station, charge and discharge are exactly regulated, and every precaution is taken to maintain the battery in the best condition of efficiency. In an automobile the discharge rate on hills has to be very heavy. The automobile is supposed to take the people in it home, and to do this the discharge may be carried too far.

The Edison battery, possibly of lower efficiency than the lead-plate battery, is almost unaffected by causes which operate disastrously on the lead-plate combination. It can be charged and discharged at high rates without hurting it. The ability to stand rapid charging may be of considerable advantage in the conditions confronting its use.

A steel grid 1/40 inch thick is the foundation for a plate. It contains in the one illustrated, Fig. 55, twenty-four perforations. For each perforation there is provided a little perforated steel box or pocket. Each pocket is made in two pieces, one entering into the other, like the top and bottom of a very shallow tin box. Each box is 3 inches long, ½ inch wide, and 3/16 inch deep, fitting the perforations accurately.

Two sets of briquettes or cakes are made, which go into the boxes, one set for the positive plates containing oxide of nickel; the other set for the negative plate containing oxide of iron. Graphite is mixed with the oxides to improve the conductivity.

If a positive plate is being made, the twenty-four boxes appertaining to it are filled with the nickel-oxide briquettes, the perforated cover is put on each, and they are placed in the openings in the grid. The whole is now subjected to high

pressure. The platen and bed of the press have ribs which corrugate the boxes. They are compressed to about one-third of their original thickness. As they expand laterally under the pressure, they are driven against the sides of the holes in the steel grids, and their sides bulge out over the ribs of the grids on both sides of them. The whole combination of grid and twenty-four pockets is consolidated thus into a strong plate, free from shake, with good electrical contact between boxes and

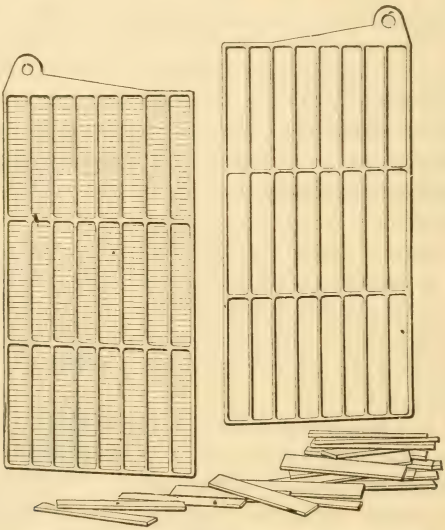


FIG. 55.—THE EDISON GRID FILLED AND UNFILLED AND BRIQUETTES.

grid. The negative plates receive identical treatment. There is no difference in appearance between positive and negative plates, the characteristic colors of positive and negative of the lead plates finding no representatives.

The electrolyte is a solution of caustic soda or caustic potash. The solution suffers no change in use except in its gradual loss of water.

The containing jar is of corrugated sheet steel, and hard-rubber supports and separators for the plates are used. The plates

are grouped in alternation, Fig. 56, just like the plates in a lead-plate storage battery, with insulating separators and supports, Fig. 57.

The action of the battery is simple. The charging current oxidizes the nickel to superoxide $Ni\ O_2$, and reduces the iron to the metallic state. In the discharge the iron is oxidized, and the nickel superoxide is reduced.

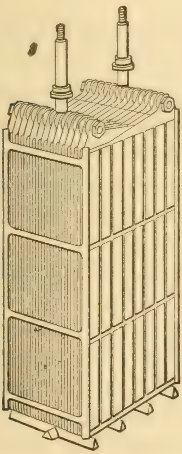


Fig. 56.—The Edison Storage Battery Elements Grouped.

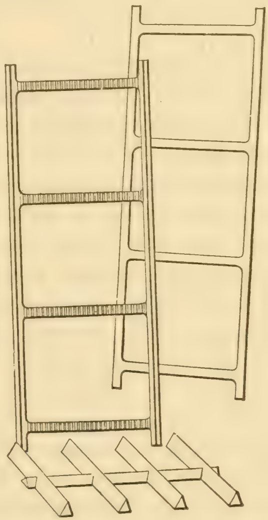


Fig. 57.—The Edison Storage Battery Supporter and Separators.

The cover is soldered to the jar, and is provided with two stuffing boxes, through which the terminals or pole pieces protrude. Another mounting on the top is called a separator. It contains wire gauze to catch any spray which may be thrown up in the charging. This acts to economize solution. Another mounting is called the filler. This is designed for the introduction of the 20 per cent solution of caustic potash which forms the electrolyte, or for the addition as required of distilled water.

It would seem difficult to add the right amount of water to

an opaque, tightly-sealed cell. A patented funnel is provided with the battery, which contains a water-level indicator, overcoming this difficulty.

Hard-rubber insulators separate the cells, and they rest upon sheets of the same material of suitable shape. Four projections on each fit into corresponding depressions in the bottoms of the cells. Four wooden buttons on the tray bottoms fit into the indentations in the India-rubber insulators beneath their projections. These trays of specially selected and prepared wood hold four, five, or six cells.

The highest voltage of discharge, immediately after charge, is 1.5 volts. The mean voltage is 1.1 volt. The normal time for charging is three and one-half hours; it can without injury be charged in an hour. A cell with fourteen positive and fourteen negative plates gave 42.5 amperes for six hours. The voltage started at 1.45, fell to 1.3 in half an hour, slowly sank to 1 volt in five hours, and then in a few minutes to 0.5 volt. At the end of six hours the voltage was almost gone.

Its weight is between 50 and 60 pounds per horse-power-hour.

The Discharge.—The normal rate of discharge of lead-plate storage batteries is eight hours. They can be discharged at a much higher rate. At a high rate of discharge the ampere-hours are less than at the slow rate. The voltage is also somewhat reduced, so that there is a large reduction in efficiency. The eight-hour rate has come to be regarded as a standard for all lead cells. If the discharge is completed in an hour by taking a very heavy current from the battery, only one-half the ampere-hours are obtained, and the efficiency is less than 50 per cent of the normal.

A rapid discharge is apt to injure the plates mechanically. If they are composite plates of pasted type, they are especially apt to be injured, the "plugs" or active portions being loosened or disintegrated. The Planté type may be expected to resist this treatment better than composite plates.

Discharge on Open Circuit.—If a battery is charged and left standing on open circuit, it loses nearly 4 per cent of its charge each day.

Manufacturer's Data.—When a battery is supplied, the manu-

facturer gives the data as regards the charging and discharging. The two rates are expressed in amperes, and are generally identical. They vary with the time for the discharge, but the charge is usually based upon a period of eight hours.

Determination of Disch.rge.—There are several ways of determining when a cell should be considered as discharged.

The voltage should not be allowed to fall below 1.70 to 1.75 volts. When it reaches this point, the cell should be put out of use and recharged. Some authorities give 1.8 volts as this limit.

The specific gravity of the acid in the cell changes slightly. It is reduced as the cell is discharged. No absolute figure can be given, as the electrolyte in different installations will often vary. The operative must learn to know his battery.

The manufacturer gives the discharge rate. If the discharge rate is multiplied by the hours, the coulombs can be calculated therefrom. A meter will tell the coulombs taken from the battery. As soon as these are equal to the coulombs deduced from the manufacturers' figures, the battery may be taken as discharged.

The positive plate, which when charged is darker in color, varying from light brown to almost black, grows lighter in tint as the battery is discharged. This change is a very poor criterion. No matter how much confidence an operative may have in his ability to judge by it of a cell's condition, color cannot be trusted as more than an approximate test.

The Charge.—After a battery has been discharged, the best practice is to charge it immediately. The rate of charging is given by the manufacturer. The voltage of the dynamo must be sufficient to produce this current against the electromotive force of the battery. As the battery receives its charge its voltage rises, so the voltage of the dynamo may have to be increased, because the voltage of the battery is opposed to or counter to that of the charging dynamo.

The voltage required for charging at any instant will always be in excess of that which the battery would give at that particular moment. The ohmic resistance of the circuit has to be overcome, as well as the counter electromotive force, and to over-

come the latter an excess of electromotive force is required from the charging dynamo. Hence there is a loss in energy involved in this difference of electromotive forces.

This is sometimes not taken adequately into account in discussing storage-battery action. The charge will be said to require a certain number of ampere hours, and the discharge will be said to give a certain number. But the ratio of these quantities does not at all express the efficiency of the battery. The watts used in charging and those given on the discharge are the data for determining the efficiency, and these depend on the voltage as well as amperage.

As the battery receives its charge, the voltage rises. The rise is more rapid at the beginning and end of the charge. When a voltage of 2.5 per cell is reached, the charge is within 90 per cent of the rated charge, and the operation may be considered complete.

Although a normal charging rate based on eight hours' charging is given by the makers, this can be exceeded. If a higher rate is used, the hours must be proportionately diminished, so that the product of hours by amperes will be the same in both cases.

Specific Gravity Variation of Electrolyte.—After a battery is in working order, the specific gravity of the solution in the cells should be taken when it is fully charged and when it is discharged. These two figures, which will differ from each other by about 0.025, may be used to determine the condition of the battery subsequently. The solution in different batteries varies slightly, so for each one the specific gravity should be determined. The specific gravity of the solution when the battery is charged should be about 1,225; when discharged, about 1,200.

The reason of this variation in specific gravity can be understood from the general description of the action of the lead-plate storage battery given on page **131.** When a battery is discharged, a part of the sulphuric acid has combined with the lead and formed lead sulphate on both plates. Lead sulphate is almost insoluble in water and in dilute sulphuric acid. The acid combined with the lead is therefore withdrawn entirely from the

solution. Sulphuric acid has a much higher specific gravity than water, so that its removal from the solution reduces the specific gravity thereof. When the battery is charged, the lead sulphate on both plates is decomposed, lead binoxide and metallic lead being formed from the sulphates, and the sulphuric acid radical enters into solution, forming sulphuric acid and increasing the specific gravity of the solution.

The specific gravity is usually determined by a sensitive hydrometer. If not sensitive, it is useless for storage battery work.

Hydrometers.—Fig. 58 shows two kinds of hydrometer. One is a tube perforated at the bottom and containing beads of varying specific gravity, the heavier ones below in order of their specific gravity. A hooked tube at the top admits air. Immersed in the solution, the bulbs which float give the approximate specific gravity. The other is the regular floating hydrometer. It floats higher as the liquid is heavier, and the scale on its stem is to be read at the level of the solution.

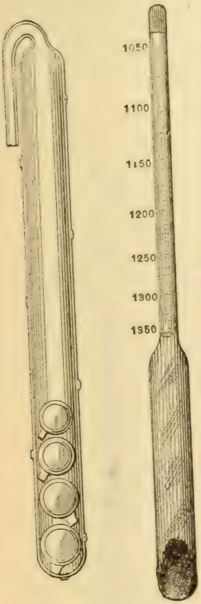


FIG. 58.—HYDROMETERS.

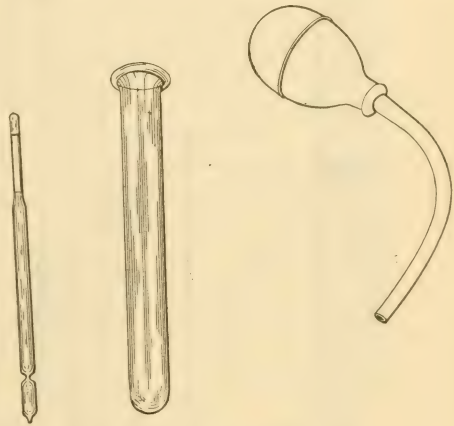


FIG. 59.—HYDROMETER SET.

The floating hydrometer may be floated directly in the bat-

tery jar. Often a heavy glass test tube, shown in Fig. 59, is used to hold it, and the test tube is filled by a pipette with India-rubber bulb. On putting the mouth of the tube in the solution of a jar, squeezing and releasing the bulb, the solution

FIG. 60.—HYDROMETER AND PIPETTE.

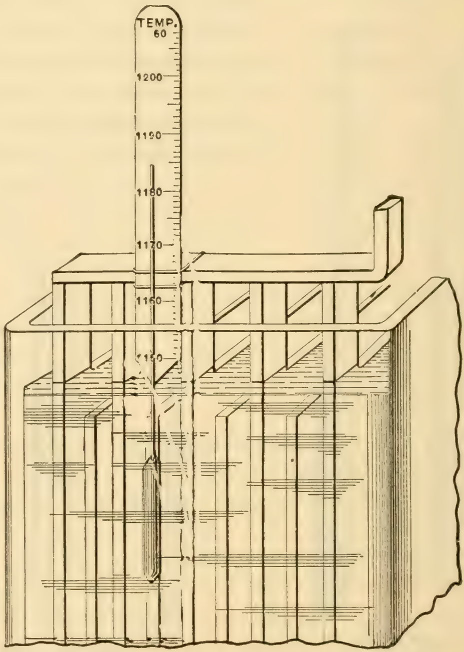


FIG. 61.—STATIONARY SCALE HYDROMETER. (Holden's.)

is drawn up and can be dropped into the test tube by squeezing the bulb. Another apparatus is shown in Fig. 60. The hydrometer is inclosed in a pipette. A stricture or annular projection at the middle of the pipette keeps the hydrometer away from the walls of the pipette. By placing the open lower end of the pipette in the solution with the bulb squeezed and releasing it,

the solution rises into the pipette and floats the hydrometer. Fig. 61 shows a hydrometer without graduation, a scale attached to the battery plate, and just touching the solution with its pointed lower end, giving the basis for reading. This obviates the reading of the water level on the stem of the hydrometer, which is rather inaccurate.

Gassing.—When a battery is receiving its charge, the water in the electrolyte undergoes decomposition, hydrogen going to one plate and oxygen to the other. The hydrogen reduces the lead oxide of the lead sulphate on the negative plate to metallic lead, with formation of water. The oxygen oxidizes the lead oxide of the lead sulphate on the positive plate to lead binoxide. Sulphuric acid is produced from the lead sulphate on both plates.

If a battery worked perfectly, it is evident from the above that no gas should be given off. Some evolution of gas may be looked for always during the last hours of the charging process. A slight bubbling may occur during most of the charging process, but much of the hydrogen and oxygen are disposed of as described above, and do not appear as gases. But when the battery is charged, the sulphate on the plates is exhausted, and can no longer dispose of the oxygen and hydrogen. These are then evolved in quantity, and the battery "gases" violently. Sometimes the solution, which is really transparent as water, is so charged with fine bubbles that it appears to be milk white.

Gas Evolution.—The evolution of gas, inevitable with storage batteries, is a distinct defect, and it is greatly to be wished that it were not inevitable. It changes the specific gravity of the solution by carrying off spray, makes the air of the battery room almost irrespirable, corrodes all brass or iron objects, and tends to produce external short-circuiting, by depositing a film of moisture on the outside of the cells and shelving. No ventilation seems adequate to overcome this trouble. The outside of glass cells should be kept dry; if of wood, oil can be applied to them to repel moisture. Such precautions as these operate to prevent leakage of current. Supports for the cells made of glass or porcelain are often used. Such are shown in Fig. 62. These contain oil in the shaded portion, but oil is not much used now,

"petticoat" porcelain supports being used instead, Figs. 63 and 64. One is placed under each corner.

All copper, brass, or iron should be excluded from the storage-battery room. Not only will these metals corrode, but there is always danger that the drip from them will get into the batteries and permanently injure them. Cables should be lead-covered.

The First Charge.—The first charging of a new battery should be at half or less than half the normal rate. Twenty or thirty hours may be given to it, instead of the normal eight hours.

If the normal charging rate is unknown, it may be found by dividing the ampere-hours of the battery by 8. A 400-ampere-hour battery should be normally charged by a $\frac{400}{8} = 50$-ampere current giving 10 to 20 amperes for the first charge.

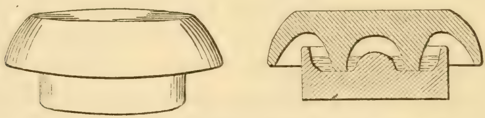
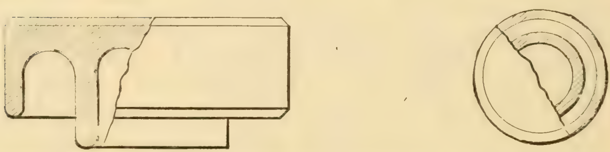


FIG. 62. OIL INSULATING SUPPORTS FOR STORAGE BATTERY.



FIGS. 63 AND 64.—PETTICOAT INSULATOR FOR STORAGE BATTERIES.

Automatic Cut-Out or Circuit Breaker.—A danger always exists in charging a storage battery. The voltage of the battery will rise, and that of the generator may fall, so that the battery will discharge itself through the generator, and will cause the latter to work as a motor. In some cases it may burn out the armature.

To prevent this accident automatic cut-outs are used, which keep the circuit closed as long as a current is passing to the

battery. Such operates by keeping the circuit closed until the current falls below a certain intensity. If it falls below this point, the circuit automatically opens. It will be found described under Circuit Breakers, Chap. XXVI. of this work. It is known as the underload circuit breaker.

English Rule for Charging.—The English manufacturers allow a charging current of 0.026 ampere per square inch of plate surface, and a discharging rate of 0.029. The charging current can be somewhat greater than the above without injury.

Overcharge.—When the battery is charged, it is wasteful to give it any more current. An overcharge of as much as 20 per cent will not hurt the battery necessarily, but excessive overcharging often repeated will injure the plates.

Prevention of Sulphating.—If a battery is discharged and left standing, a whitish deposit, probably a basic lead sulphate, forms upon the plates. This interferes with the action of the battery. Plates so affected are said to be "sulphated," and the term, whether well chosen or not, must be accepted as a technical expression. To avoid sulphating, 10 per cent to 20 per cent of the charge should be left in the battery.

If plates are badly sulphated, there is often no other cure than scraping, which has to be carefully done to avoid injury to the plates.

Sometimes a cell becomes short-circuited; dampness from the spray may bring it about, or bits of the plugs or active material from the plates, a fragment of the plate, or even some extraneous body may fall in and short-circuit a cell and discharge it before the operative suspects it. Such a cell will be in a fair way to become badly sulphated.

Too strong or too hot an electrolyte will cause sulphating. The utmost permissible limit of temperature of electrolyte is 125° F. (52°— C.). Thus in charging a battery the current must not be so strong as to raise the temperature of the electrolyte to this degree; 100° F. (38°— C.) is a safer limit.

If the sulphated plates are not badly affected, scraping may not be required. In either case the cell has to be slowly charged at not more than half the eight-hour or normal rate. The charging must be greatly prolonged.

If it is a single cell that is sulphated in a battery of a number of cells, if treated to an overcharge as described, the whole battery will be overcharged with it. This is a bad practice, although occasionally it may be adopted. If the battery has clamped or bolted connections, the cell can be cut out during the discharge and connected during the next charge or charges only of the battery, so as to get a double or triple quantity of charging. Another way, when cells are not permanently connected, is to give the defective cell a charging current during the discharge of the battery. To do this it must be disconnected, and its connections reversed. The regular discharging current will then charge the cell so connected. This is not practicable with batteries with permanent connections.

Sulphating uses up more or less of the active material of the plates. It is therefore a source of distinct injury, especially in such cases where mechanical treatment has to be resorted to for its removal.

The presence of a small amount of sodium sulphate operates to get rid of the sulphating. A little of this salt (Glauber's salt) may be added to the sulphated cell, or a little sodium carbonate may be added, which is at once converted into sodium sulphate. After the plates are restored, the electrolyte must be removed, and the cell and plates washed down; the washings are removed, and new electrolyte introduced.

Short-Circuiting of Single Cells.—The operative must watch his battery. If he notices a change in color, finds a variation in voltage or in specific gravity in any cell, it is undoubtedly short-circuited. If the short circuit is due to any external cause, the trouble can be easily located as a rule. If a foreign body, such as a plug from one of the plates, has lodged between the plates, it must be removed. A rod of wood or of other non-conducting material, or a couple of such rods used like a tongs, may be employed to pick it out. A strip of hard rubber with a hook at one end is excellent for this purpose. Sometimes a bit of the plate will project, and cause a short circuit. It must be crowded back or down. The plates should always be supported well above the bottom of the cells; sometimes they are at a height of six inches above it. Nevertheless, sediment may collect to a sufficient depth

to touch the plates and short-circuit them. In the latter case the cell may be cleaned out, or the sediment if fine enough may be syringed or syphoned off without disturbing the upper layers. Then new electrolyte must be added to replace what has been removed. As has been before stated, a metal hook or wire should never be used in removing foreign bodies from cells. Cells should be most carefully watched for short circuits to prevent sulphating, which will occur if the short circuit continues.

Sediment is sometimes removed by taking the plates out of the cell, syphoning off the electrolyte, and repeatedly flushing the cell with water and syphoning it off until the bottom is clean. But in large batteries the plates cannot be removed without danger of injuring the connections or bending them.

Buckling.—A plate buckles or bends when the charging and discharging rate are excessive or when their action varies on its two faces. Sulphating may cause it if the white deposit forms only on one face, because, as already stated, sulphating interferes with the action of the plate. A buckled plate can be straightened sometimes. It should be placed between two boards, and heavy pressure applied. A few carpenter's wood screw clamps, a vise, iron screw clamps, or an improvised lever press may be used to give the pressure. Hammering is sometimes recommended, but jarring is one of the worst things for plates, as it tends to detach the active material. Badly buckled plates may have to be discarded, if they crack badly on straightening. Buckling is apt to happen to automobile batteries when the temptation to take too much current out of them is yielded to.

Disintegration.—Plates lose their active material, often on account of sulphating; bits of lead may become detached; plugs may fall out; buckling with subsequent mechanical straightening loosens their structure. Anything that causes buckling is liable to cause mechanical deterioration. The expensive positive plates are more subject to such troubles than are the negative ones.

Setting up a Battery.—Care in handling the plates and the securing of cleanliness are the great points to be observed in setting up cells. The plates will ordinarily come positives and negatives secured together in some shape, at least nested together,

so that on lifting with both connecting bars the positives and negatives will be handled like a single mass. Between the plates are placed insulators, strips of hard India rubber, wood, glass, or equivalent insulating material, and sometimes binders go around the bunch in addition. These elements must be examined, to see that no foreign substance is lodged between them.

The cells must be perfectly clean. They are put in position at exactly the distance requisite to bring the connecting lugs together. The supporting glass plates, if such are used, and the corner insulators must all be in their permanent positions.

The elements are lifted into the cells, their supports, if such are used, being put in place. If there are loose insulators, these are put in also, and all is ready for connecting. If clamps or bolts are used for connecting, they should be painted or paraffined and wound with okonite tape.

The positive and negative plates in a cell must not touch each other anywhere. If a lead-lined cell is used, the lead lining must not be in contact with any part of the elements. A single contact will be a step in the direction of a bad short circuit.

The positive and negative plates are sometimes marked to distinguish them, but their color will be a sufficient guide. The positives are brown, the negatives gray. They must be put into the cells so as to bring the positive connections in one cell next to the negative in the next one.

The electrolyte, perfectly cold, must be added in sufficient quantity to stand half an inch above the top of the plates. It should not be put into the cells until all is ready for charging. If the plates stand uncharged in the acid, they will become sulphated. Therefore, as soon as the last cell is filled, charging should begin. The solution should be poured in with the greatest care to avoid splashing. Any that is spilled upon the outside of the cells or on the connections should be wiped off at once. The first charge should be at half normal rate for some hours, when it may be increased to normal rate. The first charging should be carried up to 2.6 volts, and the solution should be kept bubbling for some time. For subsequent charging a voltage of 2.5 is the proper limit.

The manufacturers of storage batteries are always prepared

to supply printed or special instructions for the operation of their batteries. Before setting up and putting a battery into action instructions should be obtained from the makers of the battery.

Preparing the Electrolyte.—This is a mixture of pure water (distilled water is recommended) and pure sulphuric acid. About five volumes of water to one volume of chemically-pure sulphuric acid are used.

If chemically-pure acid is not used, each carboy should be tested for hydrochloric acid, iron, and nitric acid. Other impurities will be due to the new plates or to foreign substances finding their way into the solution. The acid is poured into the water; this is important, as, if the water is poured into the acid, a sort of explosive ebullition may occur, throwing the acid about. The mixture will be quite hot. After cooling it should read 1180 to 1250 on the hydrometer. It must be completely cooled before pouring it into the cells.

A lead-lined vessel is probably the best in which to mix the solution, all things considered. Carboys will be liable to crack from the heat; enameled-iron vessels are perfectly satisfactory when new, but if the enamel is cracked iron will get into the solution. A glass or china water pitcher will answer for pouring the solution into the cells.

Impurities in the Electrolyte and Tests.—It is so important to keep the electrolyte pure that the best practice is to use distilled water to mix with the acid. The acid may contain impurities. Hydrochloric acid and nitric acid are both injurious. Copper, iron or mercury salts are all injurious; some may come from drippings from iron or copper objects in the battery room.

It is suggested sometimes to test the battery once a week for foreign substances. A few chemicals kept in solution in glass-stoppered bottles and some test tubes are all that is requisite for testing. Iron is detected by a solution of potassium ferricyanide; chlorine by a solution of silver nitrate; copper by a solution of ammonia. A little of the electrolyte is placed in the test tube, and a few drops of the reagent are added for the iron or chlorine tests. For copper, ammonia must be added and shaken with the solution in sufficient quantity to give a slight odor of ammonia,

or until red litmus paper dipped in the solution is turned blue. Iron gives a blue precipitate; chlorine a white one; copper a blue color. For testing for the presence of nitric acid, dissolve ½ gramme diphenylamine in 100 cubic centimeters of sulphuric acid, and add it to 20 cubic centimeters of water. A little of the suspected electrolyte is placed in a test tube, and a few drops of the reagent added. A blue color indicates nitric acid. For mercury, immerse a polished bit of copper in a sample of the electrolyte. A gray coloration on standing will indicate mercury.

If nitric acid is detected, it must be got rid of, if present in considerable quantity. Sometimes the cells have to be flushed out with clean water and new electrolyte introduced.

Nitric acid is more apt to be found in new batteries, where it has been used to corrode the plates before forming. The manufacturers should see to it that no nitrates are present in plates that leave the factory. Chlorides are sometimes to be found in new chloride plates. Once a battery is running satisfactorily and has been found free from impurities, frequent testing should not be required.

Indications from Gassing.—The evolution of gas, or "gassing," is an indication of completion of charge. The gassing of the cells should be watched. If at the end of a charge any cell or cells do not gas freely, it indicates that they are sulphated. When a voltmeter or hydrometer is not at hand, or when no account has been kept of the ampere hours of a charge, the cells may be made to gas freely for twenty minutes, to make certain that the charge is complete.

Cadmium Plate.—For testing the voltage of individual cells, a plate of cadmium attached to a wire is employed. The wire must be most thoroughly insulated, to prevent local action between it and the cadmium. A preferable construction would be to use a plate of cadmium with a lug or extension, the whole in one piece, and thus avoid the necessity of having an insulated wire. The plate may be a couple of inches square. Cadmium in its electro-chemical relations lies between the positive and negative plates of the lead plate storage battery, so that it is positive to one and negative to the other. It is used by inserting it in the electrolyte; a voltmeter is placed in circuit with the cad-

mium plate and the positive and negative plates alternately. The highest reading will be between the cadmium and positive plate. If the sum of the readings is 2.5 volts it indicates that the battery is charged. A very low reading in the neighborhood of zero indicates a short circuit which must at once be attended to. The cadmium plate should be wet before use, and no bubbles should be allowed to accumulate on it when in use, as they may vitiate the readings.

Connections for Charging from Lighting Circuits.—The diagram, Fig. 65, shows the connection for charging from a 110-volt incandescent lamp circuit. At K S is a knife switch with safety fuses. Lamps enough, shown at L, are placed in parallel to give sufficient current, and the group is connected in series with the battery as shown. The combination is connected across the circuit. Suppose the source is a 110-volt circuit, and that the name plate on the battery case or the manufacturer's instructions give 5 amperes as the charging rate. A 110-volt 16 c. p. lamp takes ½ ampere of current; a 110-volt 32 c. p. lamp takes

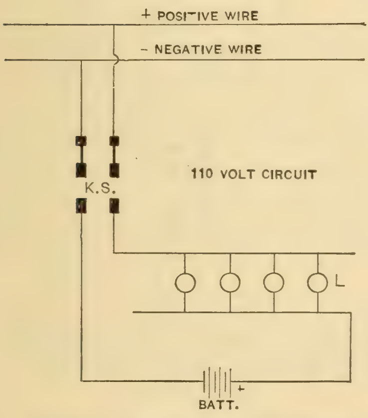


FIG. 65.—CHARGING A STORAGE BATTERY FROM A 110-VOLT LIGHTING CIRCUIT.

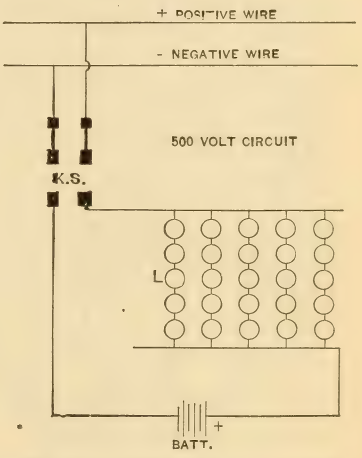


FIG. 66.—CHARGING A STORAGE BATTERY FROM A 500-VOLT LIGHTING CIRCUIT.

1 ampere of current. Ten 16 c. p. lamps or five 32 c. p. lamps in parallel at L would give 5 amperes of current.

The diagram, Fig. 66, shows the connection for a 500-volt circuit. Here, owing to the higher voltage, five lamps are needed in series, and five sets in parallel at L to give 5 amperes. K S is the knife switch.

In the diagram, Fig. 67, is shown the application of a rheostat. It must have current capacity to carry the charging current, and resistance enough to reduce to the requisite voltage. Suppose a

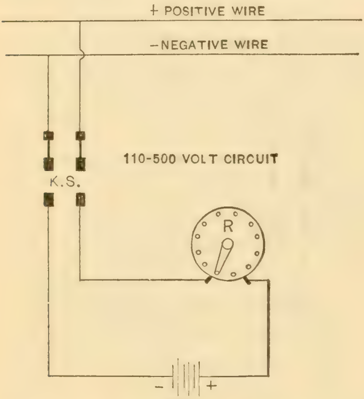


FIG. 67.—CHARGING A STORAGE BATTERY WITH A RHEOSTAT.

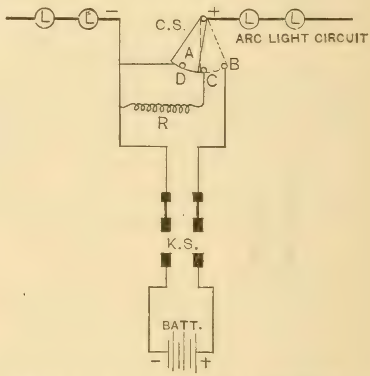


FIG. 68.—CHARGING A STORAGE BATTERY FROM AN ARC LIGHT CIRCUIT.

battery is to be charged at 6 volts from a 110-volt circuit at a rate of 5 amperes. By Ohm's law we have:

$$\frac{110 - 6 \text{ volts}}{5 \text{ amperes}} = 20.8 \text{ ohms.}$$

The rheostat must be set at 20.8 ohms resistance.

Charging from the incandescent light system is said to be a cheap way of charging. If there are cells enough to absorb 100 volts in the charging, it is an efficient way of charging; if there are but a few cells, absorbing 10 to 20 or 30 volts only, it is exceedingly inefficient, and the sight of a lot of lamps glowing to secure the charging of a small battery will always be repugnant

to an engineer. Yet as the lighting companies sell current rather than watts, it may be economical if not efficient to charge batteries as described.

The diagram, Fig. 68, shows the connections for charging from an arc light system. Here absolute danger to life is present. The arc light circuit should only be used by perfectly competent persons, and the greatest care should be exercised. All permanent connections should be made when the circuit is dead. L L indicate arc lights, R a resistance, and C S a consumer's switch. The peculiarity of this switch is that the contact arm A is so wide that in swinging it is always in contact with one or with two of the contact studs, D, C, and B. In the position shown it is in contact with D and C. Almost all the current goes by way of D; a little, following the law of parallel circuits, goes through the resistance R. Let the switch be swung to the right. It first leaves D, keeping in contact with C, and the lighting current all goes through the resistance R. It next, without leaving C, makes connection with B. Again the law of parallel circuits comes into play, and the current divides itself between the resistance R and the battery; the knife switches K S are supposed to be closed. If they are open, the whole current will go through the resistance R.

Suppose the line current is 7 amperes, and that the battery requires 5 amperes, and absorbs 6 volts in charging. Then by Ohm's law the resistance R is given by the formula:

$$\frac{6 \text{ volts}}{7 - 5 \text{ amperes}} = 3 \text{ ohms.}$$

If the line current is less than the charging current, as the latter is specified by the manufacturer of the battery, the arm may be swung so far as to rest on B only. Stops must be provided, so that it is impossible to swing it so far to right or left as to break contact with B or D respectively.

The Polarity of the Circuit must be determined with absolute certainty before using. Otherwise the battery plates may be ruined. In testing the arc light circuit for polarity, the contact arm A must rest on both B and C.

The usual test is to dip wires connected to both leads of the

circuit into a glass containing solution of salt in water. The wires must be held about an inch apart. Bubbles of gas will be given off in greater quantity from the negative pole. This lead is connected to the gray or negative plate of the battery. In attempting this test with an arc light circuit, be exceedingly careful to use heavily-insulated wires. It is best to handle them by having them tied to the ends of two dry wooden rods a couple of feet long.

The experience of the last two decades of electric development has cured of bravado all electricians worthy of the name. The greater a man's experience, the more careful will his manipulation be.

Taking Out of Service.—When a battery is to lie idle for some time, it must first be charged at the normal rate. The electrolyte is then syphoned off and replaced by water. The electrolyte may be saved. Clean carboys are the best receptacles for preserving it. The cells are then filled with water immediately, and the battery is allowed to discharge until its potential falls below one volt. The discharge should be as nearly as possible at the normal rate. The replacement of the electrolyte by water will tend to increase the internal resistance, and to diminish the rate of discharge. After the battery is discharged, the water is removed, and the plates and cells are allowed to dry. In the case of small clamp or bolt connected batteries, the plates may be removed and the cells washed out and dried. The plates may be stored in the cells or elsewhere as desired. Dryness is the great point, and is very hard to insure unless the plates can be removed from the cell, so as to admit of drying it out before replacing the plates. The plates can be stored in any dry place, but should be handled with the greatest care.

Another method of putting a battery out of service is the following: The battery is first completely discharged at a low rate The elements are at once removed from the cells and put into water. The cells are emptied, the solution being saved. The cells are washed out and filled with clean water, and the elements are replaced. The water must stand over the top of the plates.

The above method can be carried out with a permanently connected battery by the use of a syphon. The solution is syphoned

off and stored in carboys. Water is poured into the cells and syphoned out two or three times, and the cells are eventually left filled with water.

Cells.—The cells of storage batteries are for small and moderate sizes generally made of glass. For special purposes, such as automobile service, hard-rubber cells may be used. For large sizes and for central station and similar work they are often made of wood lined with lead. In the latter great care must be employed in setting up, to prevent the plates touching the lead lining, as this would give a short circuit if both negative and positive touched it. Acid-proof paint is used to paint the wooden cells.

Insulation of Cells.—This must be carefully looked after. The surface on which they rest may be covered with heavy sheet glass, or porcelain or glass insulators, already described, may be used to carry them, one under each corner. If the cells are of glass, a board painted with acid-proof paint should be provided for each one, and this should rest upon the four corner insulators. The insulators may be kept in place by being pinned to the floor with wooden pins set in melted sulphur.

Making Battery Connections.—By far the best material for permanent connection is lead applied by what is technically termed "burning." Soft solder, which is an alloy of lead and tin, is recommended sometimes, but is only a makeshift.

For temporary connections, bolts or clamps may be used. These are objectionable, as they may introduce copper or other impurities into the cells. Everything in a battery room is exposed to the spray of dilute sulphuric acid. Lead is unattacked by it, and is the ideal connecting and protecting substance.

If two strips, from two sets of plates, for instance, are to be connected, their ends are cut off at an angle of 45° with the vertical. The acute corners are at the bottom of the strips. The oblique faces are scraped off with a plumber's scraper, the two sharp corners are brought together, and a clamp or trough of sheet iron is sprung on from the bottom. The cut, Fig. 69, may be referred to here. The strips must lie horizontally and in line. Thus a V-shaped cavity with its sides closed by the iron clamp is produced.

A blowpipe flame, best of hydrogen gas, although illuminating gas may be used, is the heating agent. A bar of lead is held over the V-shaped chamber and is melted by the blowpipe flame until enough drops off to fill the cavity. The flame is applied alternately to the bar and to the surfaces of the cavity. If hydrogen gas is used, no flux is needed; if illuminating gas, a little tallow will be required as a flux.

The surface of the cavity should be kept just at the melting point, so that as the melted lead drops in, it and the lead strips will melt together. When the chamber is filled drop by drop, with heating of the surfaces during the process, the result should be a homogeneous bar of lead. The least excess of heat

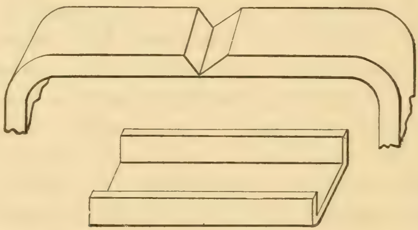


FIG. 69.—STORAGE BATTERY PLATE LUGS AND SOLDERING CLAMP OR TROUGH.

may melt the strips outside the limits of the clamp, and too little heat will make the process a failure.

The flame should be a small blue one. The apparatus can be bought at dealers in machinists' supplies.

When a number of lugs from plates are to be "burned" to a lead bus-bar, such as shown in the cut, Fig. 70, a sort of spring clamp or tongs is used whose outer ends are beveled to fit the slope of the bus-bar. Referring to Fig. 70, E is the joint in the spring clamp and F is the spring forcing its other end together. D is the top of the bus-bar whose section is shown above at B. A A are the lugs from two plates in adjoining cells. C is a plate beneath the bus-bar holding all in line.

The lugs to be connected are beveled off and the spring clamp is put on, and the beveled ends are placed against the bus-bar. The acute or lower angle of the strip or lug must touch the

bottom of the bus-bar. This gives a V-shaped cavity just as before. The surfaces are scraped before the spring clamp is put on.

Lead is melted in as before. This is a more critical operation than the other. A slight excess of heat will ruin the bus-bar.

If there are seams or drops of lead solidified on the pieces joined, they can be trimmed up. A good joint is almost indiscernible.

Neatness should not be sacrificed to strength. The joints may with advantage be left a little larger than the lugs or strips.

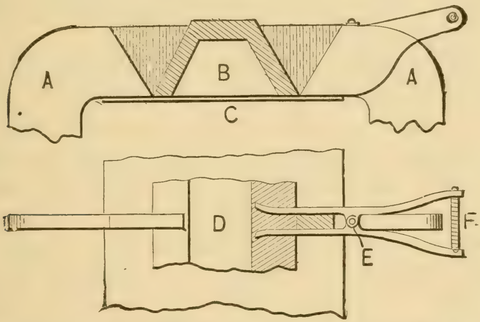


FIG. 70.—SOLDERING STORAGE BATTERY PLATE LUGS TO BUS-BAR WITH LEAD.

The principle of soldering is the uniting of two metals by an alloy more fusible than either. In "lead burning," which has just been described, the fusibility of the lugs, bus-bars, and lead used to unite them is the same. In this feature the difficulty of doing it inheres, and the same feature occasions constant risk of injury unless the operative is experienced and competent.

Practical Notes.—On unpacking a storage battery, the cells must be cleaned and examined to see if they are tight. Wooden cells must be tried by filling with water.

Shelving must stand clear of the walls, and must be insulated from the floor by glass plates or porcelain blocks.

Every fourteen days the battery should be charged up to the full charge, and then with half the normal current for a half hour. The battery should never be left uncharged for over two

days. Batteries unused for longer periods and which have stood idle are brought gradually into service by strong charging.

In slow discharge with small current intensity, not only the voltage but the specific gravity of the solution must be watched. The latter is reduced in such cases relatively more quickly than in rapid discharge. When it sinks below 1.15, the battery must be recharged, although the voltage may not be down to its allowable limit.

The acid in all the cells should have the same specific gravity, or else they will not all gas together. Equalizing the specific gravity by adding water to the cells which need it must be done when the battery is fully charged.

At least once a week cells should be examined for short circuits. Glass cells can be examined by holding a lamp behind them, so as to see if anything, such as a paste plug, has fallen between the plates. Incandescent lamps used for this purpose should have cages. Special lamps are provided for inserting into the fluid in larger cells of opaque material.

Foreign bodies, buckling of the plates, and bits of the plates or pasting can be the causes of short-circuiting in the cell. Foreign bodies must be removed by a rod of wood, glass, or hard rubber. The latter is the best. In pulling out the piece, care must be taken not to displace paste or otherwise injure the plates. On the next charging, the plates which were short-circuited can be watched to see if they gas properly. The absence of gas bubbles at the end of a charge indicates a short circuit. Never use a bare wire to remove anything from the cells.

End Cells.—This is a technical term for cells at the end of a storage battery, which are thrown in or out of circuit to regulate the voltage. A storage battery loses during the discharge over half a volt potential. If there are fifty-two cells in circuit, each one giving 2.2 volts, the total voltage will be $52 \times 2.2 = 114.4$ volts. As the battery delivers current, the voltage will gradually fall. At 2 volts it would give only 104 volts. If 114 volts is the station voltage, the first voltage named would answer, as the excess of 0.4 volt would not be too much. To maintain it, cells would have to be added in series. Thus at the 2-volt potential $114 \div 2 = 57$ cells would be required in series. When the

battery was ready for recharging, it would give only 1.8 volt per cell, and to maintain the station voltage 114 ÷ 1.8 = 63 cells would be required. This number would give a fraction less than 114 volts.

In the case assumed, the freshly-charged battery would start off with 52 cells in series. As the voltmeter fell, due to the battery losing electromotive force, a cell would be thrown into circuit. The addition of a single cell would add about 2 volts to the potential. Therefore the potential should be allowed to fall about a volt before putting another cell into series.

A bus-bar with traveling connecting springs is provided for throwing cells into and out of series. This is quite an elaborate piece of apparatus in large installations, in which the traveling

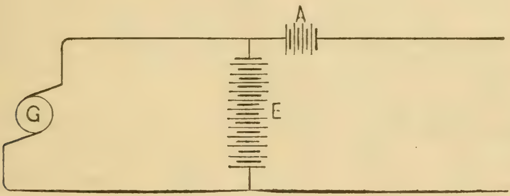


FIG. 7'.—COUNTER ELECTROMOTIVE FORCE CELLS.

contacts are sometimes operated by electric motors. For small installations switches may be provided for turning cells on and off.

End-cell regulation is very imperfect, as it involves a sudden change of two volts or thereabout every time a cell is thrown into circuit.

Counter Electromotive Force Cells.—The elasticity of action of the floating storage battery, when used in combination with a dynamo plant, is increased by the use of unformed lead plate-sulphuric acid cells, which are thus entitled. In the diagram, Fig. 71, D represents a dynamo, B a storage battery, and A counter electromotive force cells. When the dynamo is running so as to charge the batteries, it delivers current to the working circuit and forms or charges the counter E. M. F. cells, and therefore has to be run at a higher voltage than is received by the circuit,

on account of these cells operating against it, by absorbing voltage. This extra potential forces current through the battery B, so that it is charged at the same time that the district or working circuit is being supplied. When the dynamo is stopped, the main battery B supplies the lamps or other appliances. The counter E. M. F. cells are cut out one by one as the voltage due to the main battery falls, and thus serve the purpose of end cells. Seven counter E. M. F. cells suffice for charging the battery when few lamps are in use; as many as eighteen may be needed when a quantity of lamps are being lighted.

Floating Battery.—A storage battery connected across the leads of a parallel system, so as sometimes to be charged by the generating plant and sometimes to give current to the system, is called a floating battery. If it were not for the variation in voltage of the storage cell combination, it might operate automatically, but a storage battery needs constant watching, and the coupling and uncoupling of end cells and other minor manipulations required are very simple.

Charging Plant Operation.—Start the dynamo with all due precautions as to oiling and the other details.

The automatic cut-out is thrown into circuit. The operative by a current indicator must satisfy himself that the current is going in the right direction. The ammeter must be observed, to see if the proper intensity of current is being given. The voltage and amperage are regulated by the speed, or by a rheostat.

During the charging the underload circuit breaker must be watched, to see if it is in sensitive working order. It can be tested by opening and closing the main circuit. As the charging progresses, the electromotive force of the battery, which is, of course, counter to that of the dynamo, increases, and the circuit breaker will eventually fly open if the electromotive force of the machine is not brought up. If this cannot be done, one or two cells can be cut out of the series.

When the charging is complete, the main switch is opened; the motor engine or electric motor is attended to lest it should start racing; resistance is thrown into the field circuit, which is eventually opened; the brushes are lifted off the commutator, and all is brought to rest.

CHAPTER VIII.

THE FIELD OF FORCE.

The Field of Force.—A current of electricity produces a condition which is attributed to a strain or whirl in the ether. The locality or locus of the condition, as far as its detection by ordinary means is concerned, is in the vicinity of the current, and unless distorted in some way, the locus is symmetrical with respect to the current. To the mind the locus is best pictured as a cylinder through whose center the current goes. The locality is termed a field of force, and its place is called the locus. It affects iron, and is traced and may be located by its effects upon the compass needle or upon iron filings. It is no imaginary conception, for it is by virtue of the field of force that every dynamo electric generator and every electric motor works. A needle held near a magnet is attracted because of the field of force. The needle of the mariner's compass is acted on by the earth's field of force. A coil of wire rotated away from any artificial field of force generates electromotive force as its convolutions sweep through the earth's field of force. The armature of every generator produces currents and potential, which do an enormous quantity of work for humanity, entirely through the agency of the field of force.

In its effects it is a very tangible and real thing; in its theory it has to be somewhat imaginary.

Ether and Current.—A current of electricity is assumed to establish a species of strain or tension upon the ether, which strain is only detectable in the vicinity of the conductor. Theoretically, every current affects the ether through all space. A conductor through which a current passes is said to be surrounded by a field of limited size, because the intensity or strength very rapidly diminishes as its distance from the wire

increases. It is the field in the vicinity of the conductor which is easily detected. A short distance from the conductor no field can be detected, except by very delicate instruments.

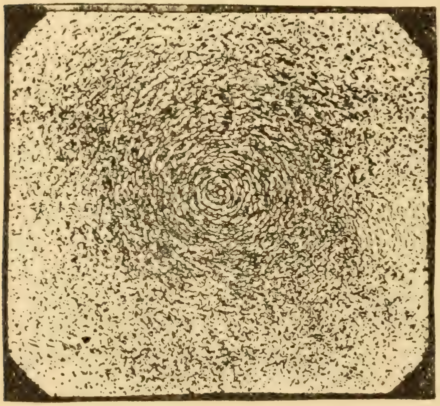


FIG. 72.—LINES OF FORCE SURROUNDING A CONDUCTOR SHOWN BY IRON FILINGS.

Detection of the Field.—If a conductor, through which a strong current passes, is led upward through a sheet of paper upon which iron filings are sprinkled, they will arrange themselves in a more or less close approach to a series of concentric circles having the conductor where it goes through the card for their common centers, as shown in Fig. 72. The filings are more crowded near the wire than on the edges of the outer circles, indicating a weakening of the ether strain as the wire is more distant. The paper may be shifted up and down the wire, and the effect will be the same at all places. The filings indicate the existence of a state of ether strain, which in general terms may be described as a cylindrical field of force. The experiment is illustrated in the diagram, Fig. 73.

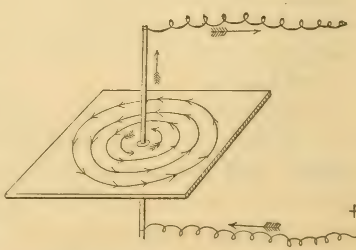


FIG. 73.—DIAGRAM OF EXPERIMENT WITH IRON FILINGS.

A compass needle held near a horizontal conductor in the magnetic meridian, through which conductor a current is passing, is deflected by the same cause which affects the filings.

The intensity of the field of force must be described in some

way, and the method adopted is to treat the field of force as a collection of lines of force. If a field is ten times as strong as another, it is said to have ten times as many lines of force in a given area.

Referring to the cuts, Fig. 74 shows the conception of the lines

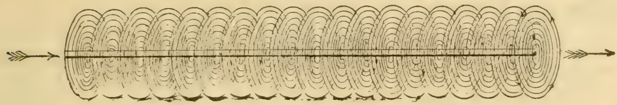


FIG. 74.—LINES OF FORCE SURROUNDING AN ACTIVE CONDUCTOR.

of force surrounding an active conductor. Fig. 75 shows the cross-sectional view of a conductor A through which a current is passing.

Lines of Force Produced by a Curved Conductor.—The effect of curving a conductor is to bring the circular lines of force together. The parts of the circles between adjacent turns are of opposite polarity, and annihilate each other, and within and without the course of the conductor, lines of force such as shown in Fig. 76 are produced. The cut will be again referred to when the significance of N and S in it will appear.

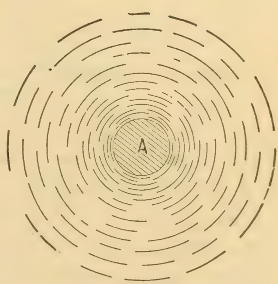


FIG. 75.—LINES OF FORCE SURROUNDING AN ACTIVE CONDUCTOR.

Motion of a Conductor in a Field of Force.—A conductor which is swept through a field of force so as to cut the lines of force has electromotive force impressed upon it, and a current will go through it, if its ends are joined so as to form a closed circuit. A current of electricity is considered or conceived of as electricity in motion. It is consistent to find some motion inherent in an apparently fixed and immobile line of force.

Accordingly, the line of force with absolutely fixed direction

may be assumed to have a whirling motion around its axis, the latter never changing. The cut, Fig. 77, shows a circular line of force, in which the whirl is indicated by arrows. The familiar smoke ring sometimes seen rising from a locomotive's smokestack has this whirl.

The whole subject is to be treated as a group of analogies rather than theory.

Direction or Polarity of Lines of Force.—In electricity there are strict relations that it is impossible to summarize or theorize upon without appealing to assumed motion and direction. Polarity, which is certainly direction, is familiar to every child in the north and south poles of his magnet. The magnet is

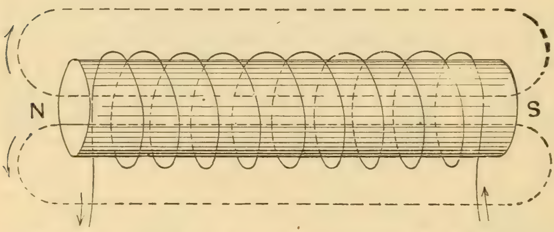


FIG. 76.—LINES OF FORCE PRODUCED BY CIRCULAR CURRENT.

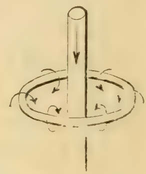


FIG. 77.—SMOKE RING.

the most familiar producer of lines of force, and their polarity or direction is fixed by assuming that they pass through the steel of the magnet from the south pole to the north pole, issue therefrom, and curving around through space return to the south pole. The electric current is already fixed as regards direction by assuming that when produced by the galvanic battery, it starts from the copper or corresponding plate and goes through the outer conductor to the zinc plate. Assume that a current of electricity is passing through a conductor pointing directly at us. If the current is coming "end on" toward us, the lines of force surrounding it will be in planes at right angles to the wire and may be circular or otherwise, but will form closed lines around the conductor. Their direction or polarity is expressed by saying that it is opposed to the motion of the hands of a

watch or clock. It is anti-clockwise. If the current were going away from us, the polarity of the lines of force would correspond with the motion of clock hands; their polarity would be clockwise.

If a current passes through a spiral conductor, such as shown in Fig. 78, in the direction indicated by the small arrows, the direction of the lines of force produced will be shown by the large arrow. Going back to Fig. 76, page 170, the same relation is indicated by arrowheads on its lines.

If the central arrow in Fig. 78 indicated a conductor passing a current in the direction of the arrow's pointing, and the

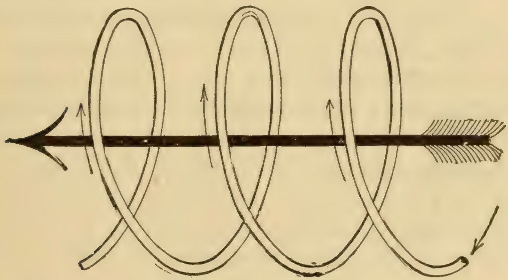


FIG. 78.– DIRECTION OF LINES OF FORCE PRODUCED BY A CIRCULAR CURRENT.

spiral was of iron, lines of force would produce the polarity shown by the arrows.

Memoria Technica for Lines of Force.—If a current is flowing directly away from us, it may be taken as representing the flight of time. The lines of force surrounding it therefore have the direction of the motion of the hands of a watch, which indicate the flight of time.

Utility of the Conception of Lines of Force.—The conception of lines of force is most useful; and Faraday, one of the loveliest characters and greatest geniuses on the scientific horizon, did the greatest service to science in his conception of them. An approximation to correctness seems sometimes more useful than the bare truth, and the bare truth in this case is that there are

no lines of force, but there is a volume of force. The entire space surrounding a current of electricity is affected or polarized by it. The current acts upon space of three dimensions or volume, not upon space of one dimension, which is the line. An infinite number of lines make space of three dimensions just as a great number of the thinnest filaments can build up a thick cable.

The field of force varies in strength with its proximity to the current, and theoretically each current affects all space. Practically, the field near the conductor is the only part strong enough to play any part in economics. This strength is expressed by saying that there are more lines of force per given cross-sectional area near the conductor than far from it.

Density of a Field.—The adjective "dense" and the noun "density" are the best words to use to specify the strength of a field. As the strength of a field is measured by the relative number of lines of force in a given cross-sectional area of it, and as it is taken as being made up of lines of force, its density expresses exactly its relative quantity of lines of force.

The Magnetic Circuit.—The entire course taken by lines of force must be a closed curve, such as a circle or ellipse. In the field of force maintained by a horseshoe or U-shaped magnet, the lines of force go through the magnet as well as through space outside it. Their path may approximate a circle or an ellipse, or be a combination of various lines and curves, but the path must be continuous. A line of force which extends out into space without limit, or a line of force which is straight for its entire length, is impossible.

The closed path followed by lines of force is called the magnetic circuit, and is shown by the dotted lines, Fig. 76, on page 170. It is closely analogous to the electric circuit.

Energy and the Magnetic Circuit.—A fundamental difference exists between the electric and magnetic circuits.

A constant electric current develops energy upon its circuit, and energy has to be expended to maintain it. Lines of force are maintained in their circuit without the expenditure of any energy. Energy is indirectly expended upon the maintenance of the field of a dynamo, simply because an electro-magnet is preferred to a natural magnet in such machines. It enables a machine to be made

smaller than it would be were a natural magnet used. A natural magnet maintains a field of force indefinitely, without expending any energy.

Counter and Forward Electromotive Force.—To create new lines of force requires the expenditure of energy; if lines of force go out of existence, they develop energy in so doing. Every current in a given circuit maintains lines of force proportional in number to its intensity. Energy has to be expended to bring these lines of force into existence, which opposes any increase of current, and this opposition is called counter electromotive force. If the current tends to cease, the lines of force in disappearing develop energy and tend to increase the current. This action is called forward electromotive force.

Increasing the strength of a field is done by increasing the number of lines of force in it, and decreasing the number of lines of force decreases the strength of a field. Energy is required for the increase, and energy is given off in the decrease.

Building up the Field of Force.—The action of an increasing current in producing new lines of force is called building up a field of force. When a circuit with a battery or other generator in it is closed, so that a current passes through it, it has to build up a field of force, and this action absorbs energy. When the field is built up, the full current due to the electromotive force passes through the circuit unopposed except by resistance, and maintaining the field without expenditure of energy.

Energy is expended in building up a field of force, none is required to maintain it. To take a homely comparison, energy is expended in carrying a weight up a flight of stairs. Once up the stairs, it is maintained there without any expenditure of energy.

Potential Energy of the Field of Force.—Energy seems, therefore, to have disappeared or to have been annihilated, which is impossible. The energy expended in forming the field of force is stored up in it. A field of force can be compared to a storage battery. In it is stored up electric energy of the potential type, which energy is expended in the production of kinetic electric energy when the field goes out of existence. This disappearance of the field takes place when the current ceases. Then the lines of force disappear at a more or less rapid rate, and as they do so

develop forward electromotive force, which, as we have seen, is of the sense or polarity of that which actuated the original current, and this forces additional current through the line. The energy of the field appears in the form of electromotive force quantity units—volt-coulombs or some multiple or fraction of them.

Energy and the Field of Force.—In recapitulation it may be repeated here that (*a*) energy is expended in building up a field of force; (*b*) that no energy is absorbed in the maintenance of a field of force; (*c*) that energy is developed in the destruction of a field of force. As a corollary from the above, it follows that (*d*) a field of force is a seat of potential energy.

Nature of the Magnetic Circuit.—A magnetic circuit is composed of a continuous path through space traversed by lines of force. The path must be continuous, and the lines of force must be closed or re-entrant curves, circles, ovals, and the like. No break can be made in the circuit; there is no such thing as an open magnetic circuit, strictly speaking.

The subject presents many analogies with the electric circuit and its phenomena. The lines of force are analogous to the current, and the current of electricity flowing at right angles to some part of their course, plays a part so like that of electromotive force, that its action is sometimes attributed to magnetomotive force. For the passage of an electric current, a conductor of some sort is required. All forms of matter can be broadly divided into relatively very good and very poor conductors of the electric current. For lines of force no such broad distinction can be drawn. Air or a vacuum is the worst conductor, but is a fairly good one at that. Iron is the best conductor, yet as the field grows intense, and more and more lines per unit area pass through it, its relative superiority over air or a vacuum diminishes.

The electric current passes through a conductor in intensity proportional to the electromotive force urging it. This follows from Ohm's law. Lines of force pass through air or a vacuum in proportion to the magnetomotive force urging them. The law of the magnetic circuit in a vacuum or in air is exactly analogous to Ohm's law.

There is very little difference in substances as regards their capability of passing lines of force until iron is reached, when at once there is a great difference; for iron may have over three hundred times the power of passing lines of force which air has.

Permeability and Permeance.—The specific or relative conducting power of a substance for lines of force is called its permeability. The conducting power of a given magnetic circuit is called its permeance.

Iron and the Field of Force.—Among all the forms of matter, iron stands alone in its relations to lines of force. Recurring to a comparison with electric current laws, it is as if copper was several hundred times a better conductor than other substances; as if there were no practical insulator for electric currents; and as if all substances except copper possessed equal conductivity. The difference between the laws of the field of force and of the electric current extends still further than the above would indicate.

Saturation.—Iron becomes a relatively poorer conductor for lines of force as more are passed through it. As the lines of force produced in iron increase in number per unit area, and are more and more thickly crowded together in it, the iron is said to approach saturation.

The permeability of iron decreases as it approaches magnetic saturation.

The permeability of air, of a vacuum, or of gases in general is virtually constant.

Different qualities of iron have different relative powers of passing lines of force—they vary in permeability.

Naturally, a thick piece of iron passes lines of force better than a thin one. It possesses better permeance. As long as the same density of field (lines of force per unit area) exists in the iron, it is subject to an analogue of Ohm's law.

Three Factors of the Magnetic Circuit.—There are three factors to be understood. They are so often referred to, that their symbols have become fixed in the science. These symbols are **H, B,** and μ. The last is the Greek letter *m* and is pronounced "mu." The **H** and **B** are invariably printed with full-faced type.

Magnetic Force.—This is sometimes called magnetomotive force, and is indicated by the letter **H** It is the cause of magnetism, and can be regarded as an effect of the electric current. As developed and used in electric machinery, it is almost always due to electric current in circular or spiral conductors. It is produced in dynamos and motors by passing an electric current through wire conductors wound around iron cores. The permeance of the cores, due to the permeability of the iron, gives a good path for lines of force.

Ampere Turns.—The current is measured in amperes and the turns of wire are counted. Multiplying them together, we have ampere turns. Electro-magnets are excited by ampere turns; the magnetizing force acting on them is often measured by ampere turns; however this force is measured, it is rigorously proportional to the ampere turns.

H may be expressed as lines of force, or as ampere turns, as a matter of convenience. The latter seems too concrete, but it is easily referred to the line of force, because the ampere turns multiplied by 1.257 gives the value of **H** in C. G. S. units.

This magnetizing or magnetomotive force acting on a magnetic circuit sends lines of force through it, each one being taken as representing a continuous curve. The whole set resemble as drawn a set of oblong or of other shaped rings.

Field Density.—The density of a field of force is indicated by the letter **B** always printed in full-faced type. It denotes the effect of **H**, which, as has been said, may be given in ampere turns. An equation similar to that of Ohm's law expresses the relation between **H** and **B**. It is:

$$\mathbf{B} = \frac{\mathbf{H}}{\text{reluctance}}$$

B is the number of lines of force which a given magnetic force **H** can force through a unitary cross-sectional area of a given magnetic circuit.

As the specific reluctance or reluctivity of air is unity, and remains so for all values of **B**; in an air path **H** and **B** vary in direct ratio with each other. If **H** is doubled, **B** is also doubled; the ratio $\frac{\mathbf{B}}{\mathbf{H}} = 1$ holds for air.

Permeability.—The relative conducting power for lines of force is so called, and is expressed by $\frac{\mathbf{B}}{\mathbf{H}}$. The permeability of air is equal to 1. Permeability is the reciprocal of reluctivity or of specific reluctance. For iron $\frac{\mathbf{B}}{\mathbf{H}}$ exceeds unity except possibly for very high values of $\mathbf{H}$, because iron has higher permeability than air for all ordinary values of $\mathbf{H}$.

The quotient $\frac{\mathbf{B}}{\mathbf{H}}$ is expressed by μ (*mu*) or

$$\frac{\mathbf{B}}{\mathbf{H}} = \mu = \text{permeability.}$$

This reads like Ohm's law, but is destroyed by the properties of iron, by which there are different values of μ for different values of $\mathbf{B}$. As $\mathbf{B}$ increases, μ diminishes for iron, never reaching but approaching unity.

Saturation of Iron.—The permeability of iron approaches unity as its field density increases. When permeability is equal to unity, iron is theoretically saturated. Saturation indicates the disappearance of the relative superiority of iron over other substances as a path for lines of force. The analogy with Ohm's law does not hold with iron until saturation is reached.

In practice iron is said to be saturated long before this value is reached. The practical saturation of iron is reached when μ is less than 500. In wrought iron such imperfect saturation is reached at 125,000 lines to the square inch as a value for $\mathbf{B}$; for cast iron, at about 70,000 lines.

No Insulator of Magnetism.—There is no insulator of magnetism. Perpetual motion has in many a poor inventor's mind appeared a possibility if an insulator of magnetism could only be found.

The line of force is an independent sort of being. Water projected from a pipe takes a parabolic course through the air unless it strikes a wall or something which will deflect it. An electric current follows its conductor as long as it is continuous. When the wire carrying it is cut or a switch is opened, the current is stopped.

When a magnetizing force, $\mathbf{H}$, is brought into existence, lines

of force go on their circuits and cannot be stopped by any material which intervenes. Metals, organic material, water, all things, are alike powerless to stop them.

The Gauss.—Air is the standard for the magnetic circuit. A magnetizing force, H, of intensity to force one line of force per square centimeter through one centimeter thickness of air is termed a "gauss." If the force, H, is doubled, two lines of force will pass per square centimeter, and so on. One gauss is equal to 0.7955 ampere turn.

Reluctance and Reluctivity.—The material of the path of the magnetic circuit resists the passage of lines of force, and is said to possess reluctance. The relative reluctance of different materials is reluctivity. The latter word is very little used. Everything in nature possesses reluctivity. That of air, being taken as the standard, is given the value of 1. Reluctance and reluctivity are the reciprocals of permeance and permeability respectively.

Synonyms for B, H, and μ.—Different authors have given so many names to these three quantities that the first two are very often spoken of as "B" and "H." The principal synonyms of B are the following: Field density, flux density, magnetic displacement, internal magnetization, magnetic induction, permeation. Of H the following are the principal: Magnetizing or magnetic force, rate per centimeter of fall of magnetic potential, magnetomotive force. Of μ the following are the principal: permeability, specific conductivity for lines of force, magnetic multiplying power.

The curves expressing the relations of magnetic force H and field density B are often called B and H curves.

B and H Curves.—The relations of B to H constantly changing are best shown by curves. The diagram, Fig. 79, gives curves for various kinds of iron. The horizontal line gives values of H, the vertical one gives values of B. As the values of B are much larger than those of H, the diagram is always magnified in the horizontal direction. If this were not done, and the scale were made the same for both B and H values, the diagram would be awkwardly high and narrow, and the H values could not be read with any degree of accuracy.

An air diagram would properly be drawn without distortion. A $\frac{B}{H} = 1$ for air, the "curve" for it would simply be a straight line rising at an angle of 45° with the horizontal. On the distorted diagram, Fig. 79, the air line would be almost horizontal. When it would cross the iron line, the point would be reached when air would be more magnetizable than iron. This point, it is safe to say, never has and probably never will be reached.

Interpretation.—The curves indicate the locus of points where any magnetization **B** is produced by any magnetizing force **H.**

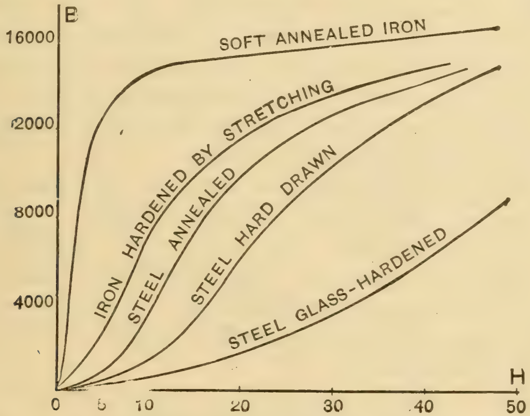


FIG. 79.—MAGNETIZATION CURVES OF IRON AND STEEL.

A vertical erected on any given point on the line **H** will intersect the curves. Horizontal lines taken from these points will intersect the vertical line **B** at the point indicating the magnetization given by the magnetizing force indicated by the point of **H** on which the vertical line was erected.

Practical Considerations.—In the building of dynamos, the permeability of the iron used for cores of armatures and of field magnets has to be known. This knowledge is essential for the calculation of their construction. Without knowing the permeabilities, the intensity of the field of force cannot be predetermined.

The curves in Fig. 79 show that soft annealed iron gives the highest values of **B** for given values of **H**. It is evident from the curves that when a density of 16,000 lines of force is produced, it is not worth while to increase **H**, as **B** will grow very slowly. But little will be gained by pushing **H** beyond 10 or 20 for soft annealed iron. Energy is expended in the maintenance of the electromagnetic field of force, under the present conditions of electric construction. Whether this should be so or not is an open question, but the case is that the value of **H** is proportional to the energy expended on the field circuit. It follows that where for a given value of **H** the highest value of **B** is reached, the best results are got for a given expenditure of energy on the field. The diagram shows that of the materials specified on the chart, soft annealed iron is best adapted for the production of an electromagnetic field.

Glass-hardened steel sweeps upward across the diagram, showing no signs of approaching saturation.

Any quantity of such diagrams could be produced. The one given illustrates their principle. The relation of **B** to **H** is most conveniently studied from such curve diagrams. Thus, if it is desired with annealed steel to produce a field of 8,000 lines of force per square centimeter, the diagram shows that a magnetizing force sufficient to produce about 15 lines of force in air should be employed.

As a matter of practice in dynamo construction and operation, **B** is generally in the neighborhood of 16,000.

Permeability Curves.—We have seen that $\frac{B}{H}$ which is never less than unity, or 1, is called permeability and is designated by the Greek letter μ. **B** varies with **H** as we have seen, but not in direct proportion to it. Therefore, varies with different samples of iron. This is because the relations of **B** to **H** vary with different irons. The curves shown on the next diagram, Fig. 80, show variations in permeability. The horizontal base line is divided for values of **B**, the existing field. The vertical line, A, is divided for the values of the quotient of $\frac{B}{H}$ or μ. The curves show how μ, which indicates the perme-

ability of different kinds of iron, varies as **B**, the magnetic field, is greater or less.

The curve of permeability often rises at first. The greatest permeability in such a case is not at the lowest value of **B**. Thus in one case for commercial wrought iron the permeability was found to be greatest when **B**, its flux density or field, was equal to 6,000 lines of force per square centimeter of cross section.

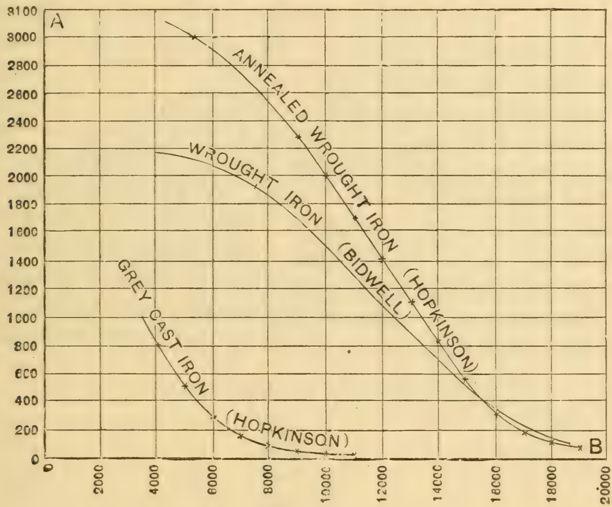


FIG. 80.—PERMEABILITY CURVES.

Soft Steel in Dynamos.—But these low flux densities have little interest from the practical standpoint. To economize in size and consequent expense, the field in electromagnetic machinery is made strong by high excitation. Annealed mild steel above 13,000 lines of force flux density has much higher permeability than soft iron. Such steel, owing to the introduction of the open-hearth and Bessemer processes, is cheaply produced and is much used for field magnets.

Annealing.—The curves on both the diagrams show that annealing is of great value. The annealing should be done after all operations tending to harden the iron are over.

Determination of Curves.—The curves in this class of diagrams represent the result of measurements made by laboratory processes. Thus in the laboratory a series of magnetizing forces are caused to produce a part of a magnetic circuit through a piece of the iron which is to be tested. The density of field produced by each magnetizing force is determined, and the two are entered in parallel columns. One column is headed **H**, the other **B**. It may be that direct values of permeability are desired. Then a third column is added. Each value of **B** is divided by its corresponding value of **H**, and the result entered in the parallel μ or permeability column.

Suppose in the experiments in the laboratory a magnetizing force of **H** $= 1.66$ has been applied to a sample of annealed wrought iron, and has produced therein an excitation or magnetic field represented by **B** $= 5000$. If we divide 5000 by 1.66, the result is 3000, or $\mu = 3000$. This gives us the figures for the top line of our three columns. Applying a magnetizing force of **H** $= 4$, we get **B** $= 9000$, and dividing 9000 by 4 we get $\mu = 2250$. The process is repeated for different increasing values of **B**, and the results of such a series of tests are tabulated below.

ANNEALED WROUGHT IRON.

H	B	μ
1.66	5,000	3,000
4	9,000	2,250
5	10,000	2,000
6.5	11,000	1,692
8.5	12,000	1,412
12	13,000	1,083
17	14,000	823
28.5	15,000	526
50	16,000	320
105	17,000	161
200	18,000	90
350	19,000	54
666	20,000	30

The three factors **B**, **H**, and μ are as essential to the dynamo or motor builder as are the three factors of Ohm's law.

Relation Between Ampere Turns and Lines of Force.—The field of force in practice as in dynamos is produced by ampere turns. If the current passing through the coils of an electromagnet is multiplied by its convolutions, it gives the ampere turns. If the ampere turns are multiplied by 1.257, it gives the value of in gausses. Thus, to produce 10,000 lines of force in a path of air, 1 centimeter long and 1 centimeter square, $\frac{10,000}{1.257} = 7954$ ampere turns will be required.

Leakage of Lines of Force.—As there is no insulator for lines of force, their escape from the path laid out for them is to be anticipated. A submarine cable will lose current if badly insulated, and a magnet core cannot be insulated as regards lines of force, because there is no insulator of magnetism, and hence its lines of force must leak.

The iron used for magnet cores possesses several hundred times higher permeability than that of air, copper, or other material. The core of a field magnet therefore retains within itself a great proportion of the lines of force, but many leak across from one limb to the other. The perfect magnet would have no leakage, and the lines of force in undiminished numbers would issue from one pole and curve around through the air to the other pole.

The leakage is greatest where the parts of the magnet core or other path of the greatest difference of polarity approach the closest. If the poles come close together, the air in their neighborhood will possess the greatest density of field and the leakage may be the greatest in their vicinity. An armature brought near the poles draws the lines of force into itself, modifying and reducing the leakage.

The relative amount of leakage is expressed by a figure called the coefficient of leakage. This expresses the ratio of total field to useful field. The latter is composed of the lines of force which go through the armature. On dividing the total lines of force existing in the circuit by those going through the armature, the coefficient of leakage is obtained. It varies from 1.15 up to 2.00 or more. If the latter figure holds, it indicates a loss of one-half the excitation. The larger the electromagnet,

the lower is the coefficient of magnetic leakage. In the large modern dynamo the leakage coefficient is very small.

A high degree of magnetization decreases permeability. As the permeability grows less, the leakage increases.

Stray Field.—The lines of force about a magnetic circuit can be divided into those which lie in the circuit and those which leak across it through the air or other substance. The lines of force which leak out of the circuit constitute what is called a stray field. The cut, Fig. 81, shows the stray field of the electro-magnet of a bipolar dynamo with an iron base.

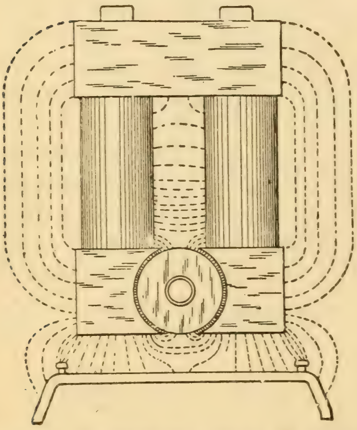


FIG. 81.—LINES OF FORCE IN SPACE SURROUNDING A BIPOLAR DYNAMO; THE STRAY FIELD.

Permeance of a Magnetic Circuit.—The permeance of the magnetic circuit of a dynamo or like machine varies with the permeability of its constituent parts, with their cross-sectional area, and with the lengths of the different parts. The permeability of the iron of the magnet core must be known, and is in good practice determined for each variety of iron used. The permeability multiplied by the cross-sectional area of the core and divided by the core length gives the permeance of the magnet core. The permeance of the armature is obtained in like manner. The air-gap permeance is obtained in the same way, except that air has a permeability of 1 always, so that unity is employed in the calculation for the air gaps where special permeability values were employed in the other parts of the magnetic circuit.

The reciprocals of the permeances or reluctances of the parts of the magnetic circuit thus determined are obtained by expressing them as denominators of fractions with numerators 1. Thus, if the permeance of one part was 1000, its reluctance

would be 1/1000. The reluctances are added together by the rule for addition of fractions, which gives the total reluctance. The reciprocal of this quantity gives the total permeance of the circuit.

Hysteresis.—When a blacksmith puts a bar of iron in the fire of his forge, it takes some time for it to come to a welding heat. If a piece of iron is subjected suddenly to a magnetizing force, it takes a certain length of time for it to acquire the full effects of the force. Just as the hot bar cools slowly, so the iron which was made a magnet by magnetizing force loses all or a part of its magnetization when that force is annihilated, but a certain time is required for this. The two cases are exactly analogous to the action of heat. The delay in changing the state of magnetization is called hysteresis.

If iron is subjected to an increasing magnetizing force, the magnetization will increase. Then if the magnetizing force be diminished, the magnetization will decrease, but not as rapidly as it increased for the same changes in **H** or magnetizing force. After the magnetizing force has been reduced to zero, the iron will retain more or less magnetization. To cause it to disappear completely, an opposite or reverse magnetizing force must be applied This will bring the magnetization to zero if the reverse magnetizing force is of the right degree of strength. Hysteresis is the tendency of magnetization to lag behind the magnetizing force.

Residual Magnetism.—The magnetism retained by the iron after the magnetizing force has ceased is called residual magnetism. It varies in amount with the quality of the iron. It tends generally to diminish with time, with changes in temperature, with other molecular and mechanical factors and actions, so that its permanency is variable.

Hysteresis is due to or is a phenomenon of residual magnetism. It therefore is of higher degree in steel than in soft iron, because steel retains more residual magnetism than soft iron does.

Hysteresis Curves.—Its action is shown in hysteresis curves. In the diagram, Fig. 82, are given curves from Ewing, indicating the action of hysteresis in an annealed steel piano-forte wire. The horizontal lines of the diagram are divided for positive and

negative values of the magnetizing force, **H**, from 0 to 100 and to —100. The vertical lines are divided for values of **B** from 0 to 15,000 and 0 to —15,000. The magnetizing force **H** applied by degrees gave the values of **B** indicated by the curve starting from 0. Thus, for **H** = 10 we have **B** = about 1800, for **H** = 50 **B** = nearly 12,000, and for **H** = 90 **B** = (a little more than) 14,000. The magnetizing force was now reduced, when the left-hand curve gives the effects of residual magnetism. On the reduction when **H** = 0 **B** = (a little more than) 10,000, and this value of **B** = 10,000 is the residual magnetism. To reduce **B** to 0

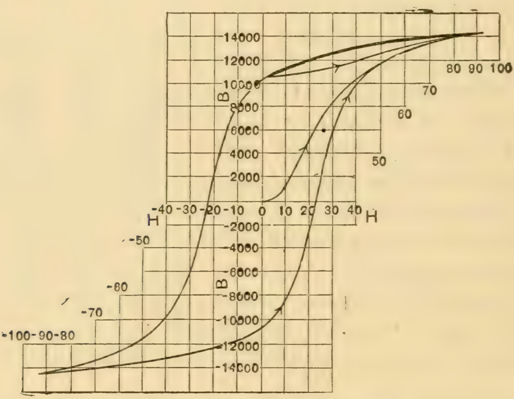


FIG. 82.—HYSTERESIS CURVES.

a demagnetizing force of **H** = (about) —23 is needed. On further applying minus values of **H**, opposite magnetism is induced in the steel until **H** = —90 a value of about —14,000 is reached for **B.** If now **H** is brought back to zero, **B** = (a little more than) —10,000, just as before the positive values of **B,** and this again is permanent magnetism of opposite polarity to the preceding. As before, **B** becomes zero when **H** has the same numerical value as before, but of opposite sign, or **H** = (about) 20 when **B** = 0. On increasing **H**, the value **B** = (a little more than) 1400 is reached when **H** has its old value of 90.

The curves give an open figure; they inclose an area, and the

whole resembles an indicator diagram. Like the latter, it represents a cycle which could be repeated indefinitely.

Loss of Energy Due to Hysteresis.—The area is proportional to the energy converted by hysteresis into useless heat.

The loss of hysteresis affects the operations of much electromagnetic machinery and of alternating-current transformers.

Hysteretic Constant.—A very simple formula for the loss has been produced by C. P. Steinmetz. Calling h the loss measured in ergs due to hysteresis per cubic centimeter of iron and for a single cycle, the formula reads as an equation:

$$h = \eta \mathbf{B}^{1.6}$$

The Greek letter η (eta) is a constant called the hysteretic constant. The equation holds good for a frequency of cycles of alternation up to 200 per second. This is twice that of standard alternating current systems. Remembering that 10^7 ergs are equal to one watt or volt-ampere, we can at once see just what waste of energy there may be occasioned by hysteresis in any case.

The hysteretic constants for various qualities of iron are given in the table.

Very soft iron wire	0.002
Most ordinary sheet iron	0.004
Soft annealed cast steel	0.008
Cast iron	0.016
Hardened cast steel	0.025

To get the loss in watts from the above, it is simply necessary to substitute the proper coefficient for η in the equation and divide by 10^{-7}, or what is the same thing, to multiply by 10^{-7}. Suppose the material used had the coefficient 0.003. The watts loss would then be equal to $0.003 \times 10^{-7} \times \mathbf{B}^{1.6} \times n$. The number of cycles indicated by n has to be introduced, because Steinmetz's original equation refers to a single cycle only.

When a magnetizing force is applied without change to a piece of iron, its magnetization increases sometimes for half an hour or more, sometimes to the amount of several per cent of the magnetization. This is termed viscous hysteresis by Ewing, its discoverer, and sometimes it is termed magnetic creeping.

CHAPTER IX.

MAGNETS.

The Electro-Magnet.—If a bar of iron is inserted in the axis of a coil of wire through which a current is passing, it will become magnetized and will attract iron. If free to move, one end, and always the same end, will point toward the north pole of the earth; not directly in that direction, except over a limited area of the earth's surface. Turning back to page 170, we see in Fig. 76 the diagram of a straight electro-magnet. The letter N indicates the north-seeking end of the pole, the letter S the south-seeking end. They are generally called the north and south poles of the magnet.

Tractive Force of the Electro-Magnet.—A piece of iron by presenting a good path for the lines of force in the vicinity of an excited electro-magnet virtually concentrates a number of them within itself. Other things being equal, a line of force tends to become as short as possible, acting something like an India-rubber band. Hence the lines extending from magnet face to armature tend to become as short as possible, and this tendency pulls the armature toward the magnet, just as if a multitude of India-rubber bands connected the two.

Spreading of Lines of Force.—In air lines of force spread apart, which might seem to contradict the above. But the lines not only tend to shorten their paths, but do not easily change direction. A line starts out straight from the surfaces of a magnet, and curves gradually toward the other surfaces. This tendency to start straight (normally) from a surface gives the lines of force a feather-like contour.

Illustrating Lines of Force About a Magnet.—The cut, Fig. 83, shows the direction of lines of force about the north and south poles of a magnet, as shown by iron filings on a card or

slip of paper. All these effects shown by iron filings may be made to give permanent records by using a piece of blue print paper, such as employed by draughtsmen. The paper is placed over the poles in a horizontal position in a somewhat obscure place. The filings are dusted on the paper, which may be tapped or shaken a little. It is exposed to strong daylight or sunlight with the filings in place, and is then soaked in water, the filings first being removed. Very interesting prints can be made in this way.

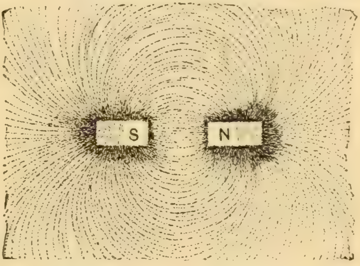


FIG. 83.—MAGNETIC LINES OF FORCE SHOWN BY FILINGS.

Spiral Electro-Magnet.—If an active conductor is surrounded by a spiral of iron, as shown in Fig. 84, the spiral will become magnetized and will become a magnet, with poles at N and S. Fig. 78 may be referred to in this connection.

U-Shaped Electro-Magnets.—The horseshoe or U-shaped electro-magnet is a type which has been very extensively used. The core represents a portion of a circle, three sides of a rectangle or some similar form, and generally two coils of wire are wound

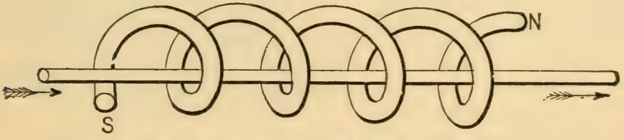


FIG. 84.—SPIRAL ELECTRO-MAGNET.

upon two of its sides. The sides are called legs or limbs, the connecting portion of the core is the yoke. A typical magnet, such as used in telegraph instruments, is shown in Fig. 85. Another wound with coned coils of wire is shown in Fig. 86. The wire is wound in opposite directions on the two legs of U-shaped magnets, as indicated in Fig. 87, in which arrows are

used to show the direction of the current around the core, whose poles, marked N and S, are supposed to face the observer.

A powerful form is that proposed by Silvanus P. Thompson and

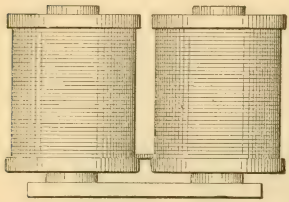


FIG. 85.—TYPICAL INSTRUMENT ELECTRO-MAGNET.

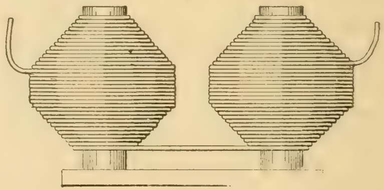


FIG. 86.—ELECTRO-MAGNET WITH CONED COILS.

shown in Fig. 88. A thick, short magnetic circuit is provided by the core of this shape.

The magnetic circle, Fig. 89, is very similar, and shows how a U-shaped magnet can be excited by a single coil. This form is made for lecture purposes about three-quarters inch thick, bent

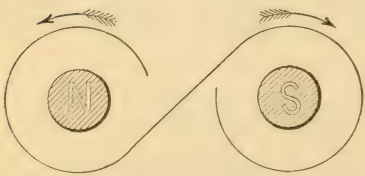


FIG. 87.—WINDING OF A U-SHAPED ELECTRO-MAGNET.

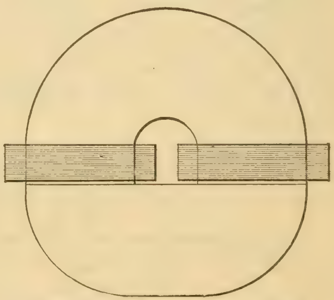


FIG. 88.—S. P. THOMPSON'S ELECTRO-MAGNET.

into half circles of about two inches internal diameter. It is exceedingly powerful, presenting a path of high permeance for the lines of force.

Joule's electro-magnet, Fig. 90, is a very old form, and one which has given very high tractive power. It was one of a num-

ber of forms of electro-magnet devised by J. P. Joule in the first half of the last century. The volt-coulomb or joule is named in honor of this distinguished scientist.

The hinged electro-magnet, Fig. 91, needs no armature. When a current is sent through its coils, the two legs swing together and their ends touch each other.

An example of a U-shaped magnet with a single coil is seen in Fig. 92. This type is called by the Germans a limping magnet, which S. P. Thompson renders club-foot. A pivoted armature is provided for these particular magnets.

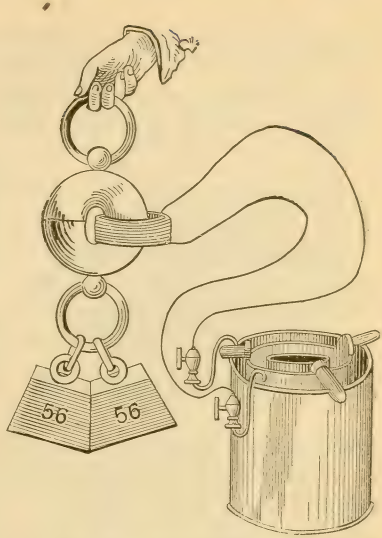


FIG. 89.—MAGNETIC CIRCLE.

Annular Chambered Magnet.—A number of electro-magnets whose exciting coils are contained in annular chambers or grooves have been devised. One used for lecture experiments is shown in Fig. 93. It may be called the electro-magnetic Magdeburg hemisperes. The magnet and armature are indicated by *a a* and are identical. The section of one, A, is shown with the exciting coil C. The iron-jacketed electro-magnet, Fig. 94, is practically one part of the above device, and is intended to attract a flat armature.

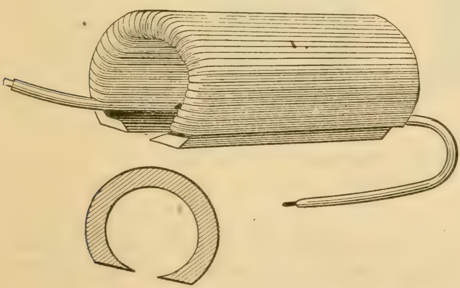


FIG. 90.—JOULE'S ELECTRO-MAGNET.

A practical application of this type is shown in the electro-

magnetic clutch, Fig. 95. Brushes B B bear upon insulated rings C C on the hub of a band wheel, which is free to rotate on a shaft. Current entering by the brushes excites the annular coil, which magnetizes the band wheel and draws it against the disk A A. The latter is keyed to the shaft and rotates with it. When the disk and free band wheel are drawn together, the wheel has to turn with the shaft.

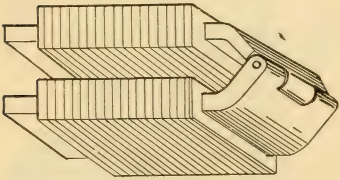


FIG. 91.—HINGED ELECTRO-MAGNET.

Electro - Magnetic Tractive Power.—A pair of wheels may be drawn together by a coil, as is shown in Fig. 96, thus one wheel being caused to grip or press against another, so as to turn it. The arrangement shown is of very limited application, and owing to the poor magnetic circuit, is far from efficient. A better arrangement is shown in Fig. 97, where a current of electricity passed through a coil car-

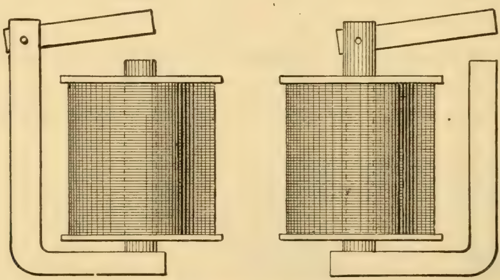


FIG. 92.—"CLUB-FOOT" OR LIMPING ELECTRO-MAGNETS.

ried by a car wheel increases its traction on a rail. The coil is annular and lies in the groove around the wheel. The current enters by brushes, as in the clutch just illustrated.

Multipolar Magnets are shown in two examples—Joule's "zig-zag," Fig. 98, and Roberts', Fig. 99, electro-magnets. These, in the light of what has been said, explain themselves. In them the

usual letters N and S indicate north and south poles, and the arrows indicate the direction of the current.

Various Armatures.—Cam mechanism due to Robert Houdin, the famous French magician, is shown in Fig. 100. E is the electro-magnet attracting its armature *a*. The cam A acts upon B. By varying the shapes of the faces of the cams, all sorts of results in the motion of the distant rod can be reached.

The armature shown in Fig. 101 is attracted upward from the position shown in the dotted lines when the magnet is excited. It also presses against the drum, which is part of the core, and rotates it so as to turn the gear wheel on the further end of the shaft. A spiral spring may pull upon the short arm to draw the armature back. This operates like a ratchet and pawl mechanism, as it only operates to turn upon its up-stroke.

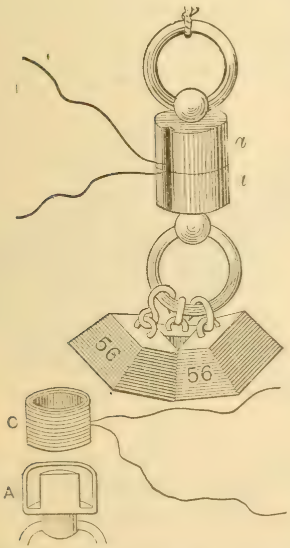


Fig. 93.—Annular Chambered Electro-Magnet.

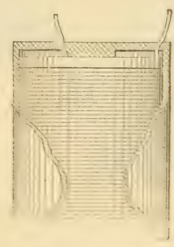


Fig. 94.—Iron-Jacketed Electro-Magnet.

In this magnet the core must be free to turn in the coil. In Fig. 102 is shown another magnet with rotating core. A is the rotating core, turned in one way by the pull upon the armature projecting from its lower end. The arm D is of brass, C is of iron. The core B is fixed.

Other pivoted armatures are shown in the cuts, Figs. 103 and 104.

The Natural Magnet is a mineral consisting of a combination of iron and oxygen, whose composition is indicated by the chemical formula, Fe_3O_4. The mineral is called magnetite, and is characterized by being attracted by the magnet just as iron is, only not so powerfully. Some samples of magnetite do more than this, as they attract iron themselves. Such are natural magnets, known to the ancients as the lodestone. The attractiveness for iron is localized in each piece, being at a maximum at certain points. These points act upon the compass needle, each repelling one end of it and attracting the other end. If the mineral were suspended by a delicate enough pivoting or suspension, one of the attracting points on it would seek the north pole.

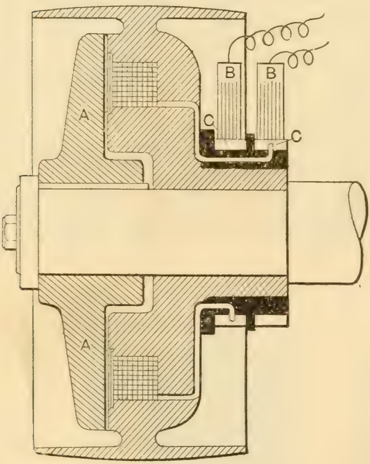


FIG. 95.—ELECTRO-MAGNETIC CLUTCH.

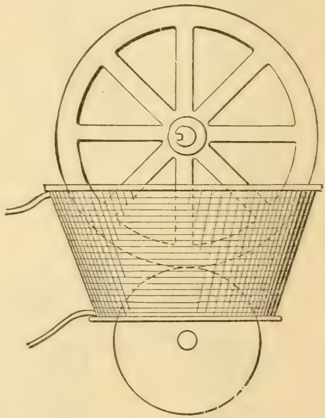


FIG. 96.—ELECTRO-MAGNETIC DRIVE.

The Permanent Magnet is a piece of steel which has been charged with magnetism, and which retains it. It attracts iron, its ends doing so most strongly; tends to point north and south, the same end always tending to the same pole; and thus determines what are generally called its north and south poles. Sometimes they are called the north-seeking and south-seeking poles.

Action of Magnet Poles on Each Other.—The north poles of two magnets tend to repel each other, and the south poles repel each other exactly the same. A north pole of one magnet attracts the south pole of another. Like repels like, and unlike attracts unlike. Magnets repel each other just as much as they attract each other.

Making Magnets by Single Touch.—One process of making a magnet is shown in Fig. 105. A bar of steel lying on a table is stroked from center to end with one pole of a permanent magnet, the arrow showing the motion. The stroking magnet is returned through the air to the center of the steel bar, and a second stroke

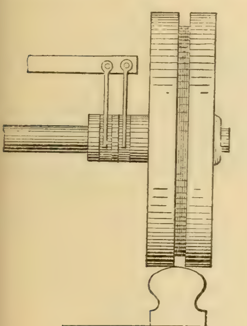


FIG. 97.—ELECTRO-MAGNETIC CAR WHEEL.

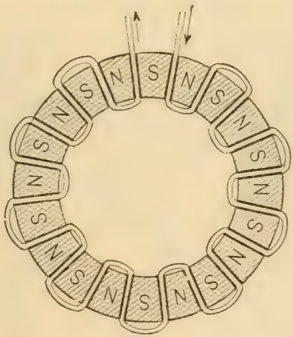


FIG. 98.—JOULE'S ZIGZAG ELECTRO-MAGNET.

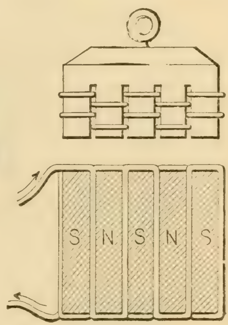


FIG. 99.—ROBERTS' ELECTRO-MAGNET.

is given. This is repeated a number of times, and then the same operation is gone through with the other pole of the magnet on the other half of the bar. The end of the bar stroked with the north pole of the magnet will be a south pole and *vice versa*, as indicated by the letters N, N and S, S in the cut. This process is called single touch. The stroking may be done for both halves with two magnets simultaneously, as described above for one. The north pole of one magnet and the south pole of the other are brought together or nearly so on the center of the bar, and simultaneously moved out along it, are swept back to the center through the air, and the stroking is repeated. A little bit of wood may be placed across the center of the bar to keep the magnets from touching each other at the beginning of the stroke.

Making Magnets by Double Touch.—For this the opposite poles of two magnets are brought close together, separated by a slip of wood or pasteboard, the magnets being inclined at an angle of over 90° to each other, like a V with very wide angle, Fig. 106. The apex is placed on the center of the bar, and is moved ten to twenty times slowly back and forth over the whole length of the bar.

In both single and double touch the effect is increased by resting the ends of the bar to be magnetized upon the opposite poles

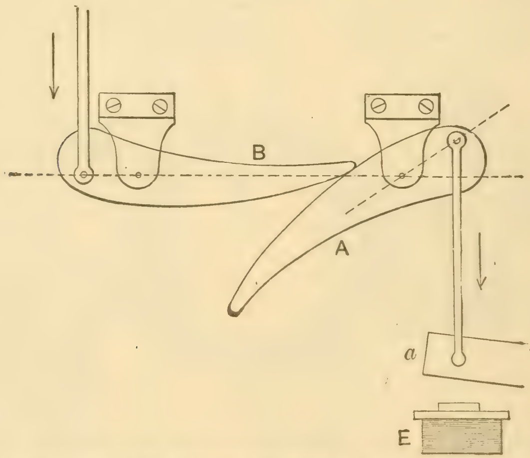


FIG. 100.—CAM MECHANISM FOR ELECTRO-MAGNETS.

of two other magnets. The poles must be the same as those of the magnet with which the stroking of the end in question is done.

Making U-Shaped Magnets.—This type of magnet is universally called a horseshoe magnet. A bar of iron of this shape may be magnetized by stroking with another horseshoe magnet, from near the bend to the ends, or from ends to the bend. As for straight magnets, the magnet must be returned through the air. A piece of iron should be laid across the ends during the process. An excellent way of magnetizing U-shaped bars used for voltmeter magnets is to place the ends of the bar against the two

poles of a powerful electro-magnet. Each end touches its own pole, and the adherence is strong. The operative now rocks it back and forth a number of times as it adheres to the electro-magnet, thus slightly jarring it and causing it to become permanently magnetized.

Magnetizing by Coil and Electro-Magnet.—A compactly-wound coil of wire was proposed by Elias of Haarlem for making magnets. Through such a coil a current was passed, and the coil was moved from end to end of the bar to be magnetized. The coil may be slid thus over a U-shaped bar while its ends are in

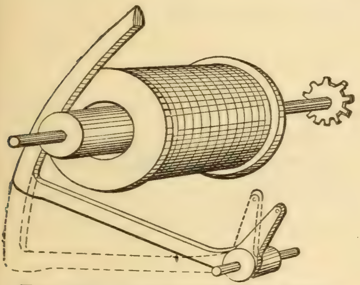


FIG. 101.—CALOMBET'S ELECTRO-MAGNETIC PAWL.

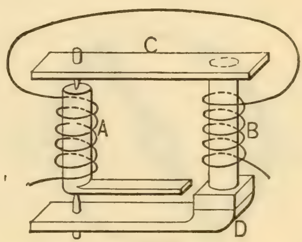


FIG 102.—WATERHOUSE'S PIVOTED ARMATURE.

contact with a powerful electro-magnet. A successive turning on and off of the current of the electro-magnet is used sometimes. Another suggestion was to apply the steel bars while red hot to the poles of an electro-magnet, and to pour cold water on them while there.

Steel for Magnets.—Tungsten steel is considered the best material for permanent magnets. Hopkinson gives the analysis of such a steel:

Iron	95.371
Carbon	0.511
Manganese	0.625
Silicon	0.021
Phosphorus	0.028
Tungsten	3.444

Chrome steel containing 0.687 carbon and 1.195 chromium and no tungsten also gave Hopkinson good results.

Preservation of Magnets.—Jarring should be scrupulously avoided. The armature of a magnet should not be allowed to come against the magnet violently. It should be gently put into place. Jerking the armature off does no harm unless a positive jar or clicking is produced. A horseshoe magnet should have its armature in place when it is put away, and bar magnets should be in pairs, with poles in reverse direction and connected by short bars or armatures.

Examples of Permanent Magnets—A compound U-shaped magnet is shown in Fig. 107. The body is made of thin bars

FIG. 103.—OSCILLATING ARMATURE.

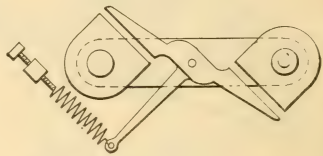


FIG. 104.—SIEMENS'S PIVOTED ARMATURE.

supposed to be magnetized separately, and then fastened together. An iron armature *a* with a hole serves to show its lifting power. Weights are attached by means of the hole. The above would often be termed a horseshoe magnet. A true horseshoe magnet is shown in Fig. 108. There the poles are very close together. Such a magnet can be used for magnetization by double touch, on account of the proximity of the poles.

An iron bar with a wheel of lead or brass mounted on its center and placed across the legs of a magnet, as shown in Fig. 109, will if it is inclined roll down the magnet around the poles and up the under side of it, actuated by the momentum of the little flywheel. In the next cut, Fig. 110, little bars of iron with disks at the ends are placed together, as at A. On bringing a magnet above them, they become similarly magnetized, and as

they lie with north pole to north pole and south pole to south pole, they are driven apart by mutual repulsion, indicated by B, B.

Polarized and Magnetized.—When magnetism is spoken of,

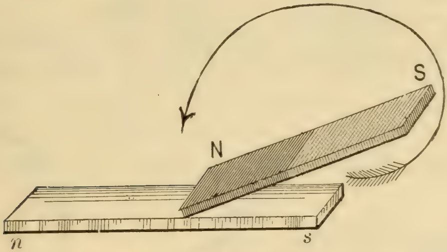


FIG. 105 —MAKING A MAGNET BY SINGLE TOUCH.

these words are synonyms. A polarized piece of steel is a magnetized one. A polarized relay in telegraphy is one whose action depends upon a permanently magnetized armature.

Constancy of Magnetism.—For instruments such as voltmeters, the critical thing is to have magnets of great constancy.

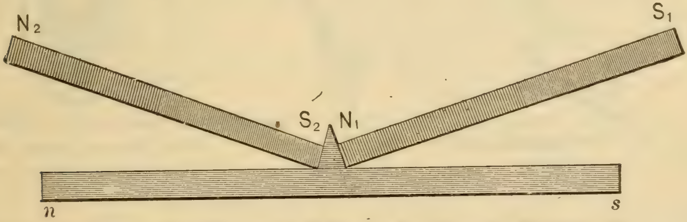


FIG. 106.—MAKING A MAGNET BY DOUBLE TOUCH.

To secure these, they must not be too strongly saturated, as such a procedure produces magnets which lose readily part of their strength.

Mutual Action of Currents—Two parallel conductors through which currents are passing attract each other if the currents are flowing in the same direction. If one current is flowing in one direction and the other current in the reverse direction, the conductors repel each other.

Ampere's Theory of Magnetism.—Based on the above facts and on the construction of the electro-magnet, the celebrated Ampere's theory of magnetism has been formulated. It accounts for the mutual attraction and repulsion of magnets, and for their tendency to place themselves in the magnetic meridian and to have one end seek the north pole.

A current of electricity is assumed to circulate around each molecule of a magnet. The cut, Fig. 111, shows the theory. It

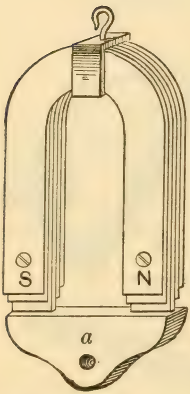


FIG. 107.—COMPOUND U-SHAPED MAGNET.

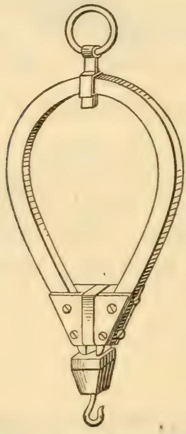


FIG. 108.—HORSES MAGNET.

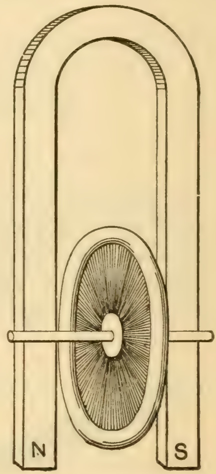


FIG. 109.—MAGNET WITH FLYWHEEL ARMATURE.

will be seen that the effect is as if a single current circulated around the outside of the magnet. The parts of the currents adjacent to each other in the interior counteract each other, and the outside currents virtually coalesce into one. This is the conception of a magnet according to Ampere's theory.

It will be seen that the current denoted by the outside arrows corresponds to the current through the windings of an electro-magnet. If the observer faces the north pole, the Amperean current, as it is called, will circulate in direction opposite to the motion of the hands of a watch. If we face the south pole,

the current will coincide in direction with the motion of the hands of a watch.

Memoria Technica.—A watch indicates seconds, and could properly have the letter S marked upon its glass. It would then represent the south pole of a magnet, its hands in their motion giving the direction of the Amperean currents. The watch has been used before to fix on the mind the relation between an electric current and its lines of force. The "S" may be taken as the symbol for "seconds" and "south pole."

Taking the face of a watch as indicating the south pole of a magnet, it tells us how the lines of force go. As the watch tells us that time flies from us, it tells us that at the south pole the lines of force fly from us. They issue from the north pole and return to the south pole through the outer circuit.

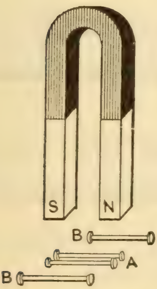


FIG. 110.—ROLLING ARMATURES.

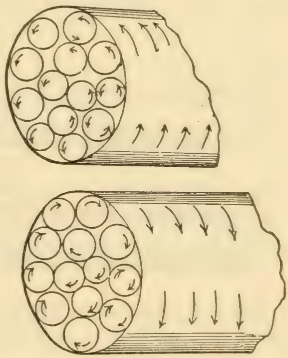


FIG. 111.—AMPERE'S THEORY OF MAGNETISM.

Ampere's Theory of Terrestrial Magnetism.—A magnet points north and south, approximately, the same pole always pointing north. By Ampere's theory this is accounted for by supposing the earth to be a great magnet, and to be encircled by currents flowing around it, approximately parallel to the equator.

If currents of like direction attract each other, then if placed at an angle with each other they will tend to coincide in direction. Currents tend to become parallel with each other, and to

coincide in direction also. If two conductors are free to rotate, and currents are passed through them, they will tend to rotate like a compass needle until parallel with one another, with the current flowing in the same direction in each.

The theoretical ampere currents of the earth force the ampere currents which are supposed to encircle a magnet into parallelism and similar direction, and thus cause the compass needle to point to the north.

Attraction and Repulsion of Magnetic Poles.—In Fig. 112 are shown two pairs of magnets. One pair has its north pole facing the south pole of its neighbor. The arrowheads indicate the direction of the Amperean currents. The currents in both poles

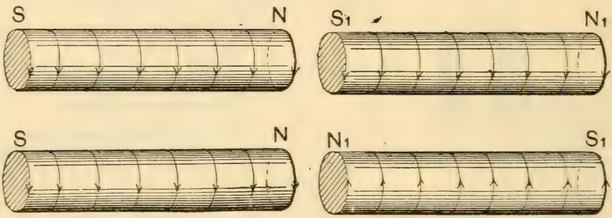


FIG. 112.—AMPERE'S THEORY EXPLAINING ATTRACTIVE AND REPULSIVE FORCES BETWEEN MAGNETS.

correspond in direction, and as currents of like direction attract each other, the north pole of the magnet S N and the south pole of the magnet $S_1 N_1$ attract each other.

This refers to the upper pair. In the lower pair one magnet has been turned end for end. The Amperean currents are now opposite in direction, and the north poles of the magnets SN and $N_1 S_1$ repel each other.

If the south poles were brought together, repulsion would also exist, because the Amperean currents would again be opposite in direction.

Action of a Current on the Magnet.—A compass needle in the vicinity of an electric current is acted on by it, and tends to place itself at right angles thereto. It never can unless the current is at right angles to the magnetic meridian, but the

tendency is present. Thus a current deflects a compass needle, if the compass is held near the conductor, unless the conductor is at right angles to the magnetic meridian, or lies nearly or quite east and west.

Remembering that the magnetic needle of the compass is supposed to have Ampere currents circulating around it in planes at right angles to its axis, this directive tendency of the compass needle will be recognized as an effort of the Ampere currents to place themselves in parallelism with the current in the conductor. If held above the conductor, the needle will be deflected in one direction; if held below, it will be deflected in the other. Ampere has devised a rule for remembering the ways in which a magnetic needle will be acted on by a current in a conductor near to it.

Ampere's Rule.—If a man were swimming with the current in the conductor and had his face turned toward the magnetic needle, its north pole would be deflected toward his left hand. This means that if the needle was above the conductor, he would have to be on his back to face the needle; if it was below, he would have to be on his face. Hence the needle will turn in reverse ways according to whether it is above or below the conductor.

If the direction of the Ampere currents be formulated in the mind, it will be seen that the above deflection of the magnets simply brings them in parallelism with and coincident in direction as regards their nearest portion with the current in the conductor.

A coil of wire traversed by a current represents a magnet. In physical experimenting, such coils called solenoids are used to illustrate the Ampere law. They will, when passing a current, tend to point toward the magnetic pole; their unlike poles will repel each other; and they will act exactly as magnets do. If an inert bar of iron is surrounded by a conductor carrying a current, Ampere's law will be exemplified, and we will have an electro-magnet.

An electro-magnet is a bar of iron around which a current of electricity is caused to flow, so as to represent the Ampere magnetizing currents of the permanent magnet. As we can make

the artificial currents very strong, and give them as many turns around the iron (called a core) as we wish, an electro-magnet can be made very strong, many times stronger than the best permanent magnet of equal weight.

FIG. 113.—CORKSCREW ANALOGY OF THE MAGNET.

Right-handed Screw Law.—The relation of north and south pole to the current circulating around a magnet core is expressed by the right-handed screw law. It is to this effect:

A right-handed screw, such as a corkscrew, Fig. 113, placed so as to coincide with the axis of the magnet and turned in the direction of the current, will move toward the north pole of the magnet. The arrows and polar letters N and S in the cut indicate the relations. This is merely another statement of the watch law.

Assuming the arrows to indicate the direction of current circulating around an iron bar S N, it will be seen that if the end N were pointed at the reader, the current would be against the motion of the hands of a watch. The end pointing thus should be and is the north pole. If the corkscrew were turned in the reverse direction, its motion would indicate a current in the opposite direction to that shown by the arrows. If the lower end were pointed at the reader as before, the current would coincide in direction with that of the hands of a clock or watch, and the pole would be a south pole.

Again, imagine a corkscrew pointed at the face and turned. If turned right-handedly, it would advance if the screw had a grip on anything. Its direction of turning would give the polarity of the lines of force due to a current moving in the direction of the observer. The reverse also holds. Both these statements express the watch-face rule for lines of force due to currents.

CHAPTER X.

INDUCTION.

Electro-Magnetic Induction.—If an electric conductor lies in a field of force, it may be in the vicinity of a magnet pole, it will be unaffected by the field, as far as any electromotive force in it is concerned. If the conductor is moved so as to cut the lines of force, or if the magnet is moved while the conductor is stationary, which brings about the same result of cutting lines of force, electromotive force will be impressed upon it. There are many variations in the relations of conductors and fields of force which have the effect of impressing electromotive force upon such conductors, and producing currents in them if they form or are part of a closed circuit. In general terms the inductive effects summarized above involve attraction or repulsion between pole and conductor.

Threading, Interlinking, and Cutting Lines of Force.—There are two general ways of taking cognizance of the action of a field on a moving conductor. It may be referred to cutting of lines of force by the conductor, or to changing the number of lines of force which pass through the space included in the electric circuit. The latter may be looked upon as a ring, or irregular circle-like lead of wire. The passing of lines of force through this circle of wire is often called threading or interlinking of lines of force. The latter expression is correct because lines of force form closed circuits of their own.

Induction.—When an electric conductor forming part of a circuit is swept through a field of force an electromotive force is impressed upon it. If the ends of the conductor were connected to a proper instrument, such as a voltmeter, the electromotive force would affect its index, and it would be evident that electromotive force actually existed. The cutting of lines of force by an electric

conductor represents the impressing of force upon or transferring of force to the conductor. The term force as last used applies to electromotive force. If the proper conditions are established the electromotive force impressed on the conductor by the field of force will produce a current. If these conditions do not exist no current will be produced. Thus there are two varieties of induction. In the one case energy in the form of volt-coulombs, or other electromotive force-quantity unit, is developed, and by the law of the conservation of energy the motion of the conductor through the field of force is resisted, so that energy has to be expended upon it to move it across the lines of force. In the other case no current is produced and no energy is required to move an open-circuit conductor through the field.

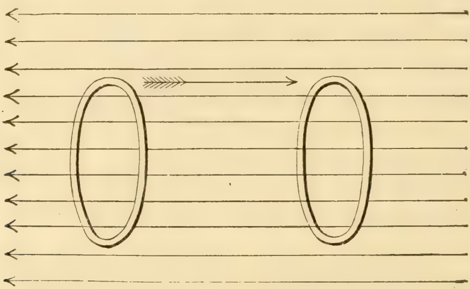


FIG. 114.—RING MOVING IN FIELD OF FORCE WITHOUT CUTTING LINES OF FORCE.

Conditions for Inducing Electric Energy.—The conditions for thus producing current are two. The conductor must form part of a closed circuit, and the number of lines of force passing through the loop or opening of the circuit must vary in number; or a portion of the circuit must cut lines of force. In most cases of dynamo generators both the latter conditions exist at once. As the armature conductors cut lines of force they vary the number of lines of force interlinked with the circuit.

Examples of Interlinking.—Assume a uniform field of force and let a ring of conducting material be moved in it. The cuts, Figs. 114 to 117, illustrate several conditions, the motion of the ring being indicated by the arrows.

In the case illustrated by Fig. 114 the ring is swept through the field of force but cuts no line of force as its motion is parallel to them. Therefore no electromotive force is impressed upon it. In the case shown in the next cut, Fig. 115, lines of force are cut, therefore electromotive force is impressed; but as the number of lines of force embraced in the ring is unchanging, no current is produced. Each half of the ring has electromotive force of the same polarity impressed on it and the two oppose each other, so that no current results. In Fig. 116 the ring is swung around so that it not only cuts lines of force, but the number of lines embraced by it is constantly varying, hence

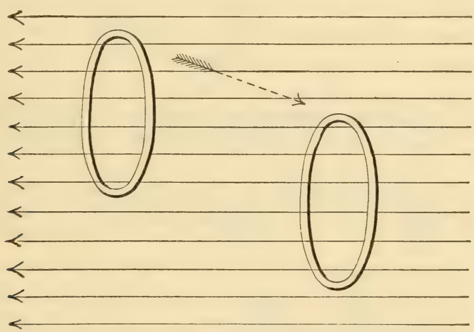


FIG. 115.—RING MOVING IN FIELD OF FORCE CUTTING LINES OF FORCE WITHOUT CHANGE OF INTERLINKED LINES.

electromotive force and current both result. In the next cut, Fig. 117, the ring is swept in a straight line through a nonuniform field of force. It not only cuts lines of force, but the number passing through it varies constantly. Electromotive force and current both are produced. In the first two cases no power is expended on moving the ring through the field; in the last two power is so expended.

Motionless Conductor in a Field of Force of Varying Density.—Where a ring or convolution of wire or other conductor is placed in a magnetic field, lines of force will pass through it, if its plane of position is at an angle to the general direction of the lines of force. Lines of force would be said to thread through

it, but would have no effect whatever upon it. We have seen that a current would flow through it, actuated by electromotive force,

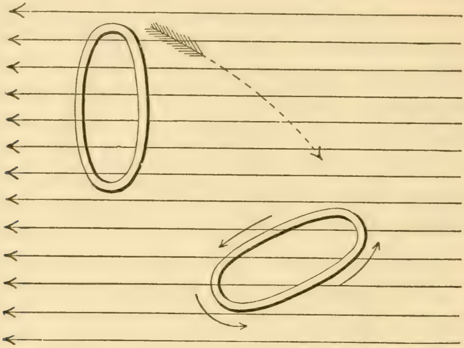


FIG. 116.—RING MOVING IN UNIFORM FIELD OF FORCE UNDER CONDITIONS PRODUCING A CURRENT.

if the wire were moved so as to vary the number of lines of force embraced by the circuit. Suppose the wire or conductor to be

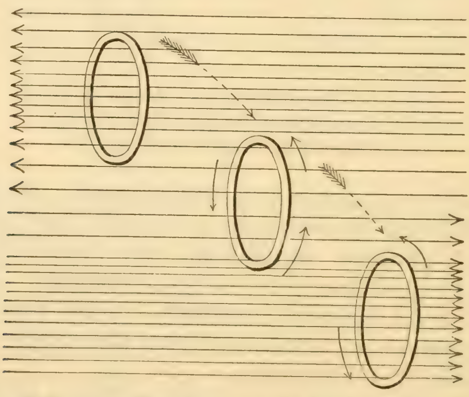


FIG. 117.--RING MOVING IN FIELD OF FORCE UNDER CONDITIONS PRODUCING A CURRENT.

kept motionless and the density of the field of force to vary. This would cause the lines of force embraced by the circuit to vary

in number. Electromotive force and current would be produced in the conductor exactly as if it were moved.

Energy Relations.—Energy would be absorbed whether the field of force was increased or diminished in density under the above conditions. The presence of the closed circuit would be the cause of such expenditure. It would by counter-electromotive force resist any change of field density which would produce energy in its conductor, and exact the expenditure of additional energy.

Fields of Force in Practice.—In practical engineering fields of force are produced by magnets, which are generally electro-magnets. They vary in the number of their poles, but follow pretty closely some general rules. The poles are nearly always of even number; for every north pole there is a south pole; the north and south poles are placed in alternation with each other. Fields of force may be moved past conductors or past coils forming parts of circuits; or the conductors and coils may be moved past them; or the relations of field to conductors or coils may be kept changing, as in inductor generators. In all such cases electromotive force is impressed on the circuits. The conductors or coils which are thus treated form part of armatures, and constitute the active portions of the armature windings. The effect of the processes is to cause the number of lines of force interlinked with the circuit to vary. A variation of 10^8 lines of force per second produces an electromotive force of one volt.

Direction of Current Induced by Cutting Lines of Force.—If the north pole of a horizontally placed magnet face the observer the lines of force will come out of it toward him, will curve around and pass through the space surrounding the pole away from it to the south pole. If a perpendicular conductor is swept from left to right across the north pole an electromotive force will be induced in it, tending to produce in it a current from above downward. Let a letter N be marked upon the pole. Rule lines upon the end parallel to the oblique stroke of the N. Cut a narrow slit in a card and holding it with the slit vertical move it to right or to left. The lines will appear through the slit like a series of dots, and will appear to move up or down—up for a motion to the left, down for a motion to the right. Their

apparent motions indicate the direction of currents induced in a vertical conductor moved across the north pole, to left or to right. For the south pole the directions are the reverse.

The cut, Fig. 118, illustrates the principle. In it the south poles are diagonally shaded in the opposite sense to the north pole. The same process of using a slotted card will show the direction of currents in a conductor swept across them.

In the cut the arrows *a b* and *c d* indicate the direction of current induced by motion in the direction of the dotted arrows. With motion in the other direction the currents would have the reverse directions.

Two Systems of Induction.—Electro-magnetic induction can be referred to two causes. One cause is the cutting of lines of force

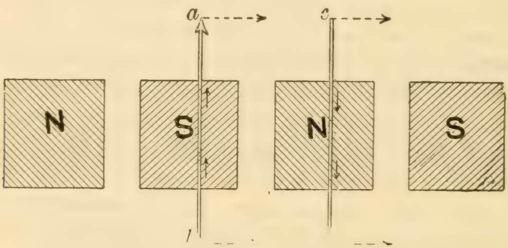


FIG. 118.—DIRECTIONS OF INDUCED CURRENTS.

by conductors. This generally, as far as effective, has the result of changing the number of lines of force threading the circuit. The other way is to directly change the number of lines of force threading the circuit, without reference to cutting them by conductors.

The first cause is represented by the conductors on a drum armature, one of which is indicated in diagram in Fig. 119; the second is represented by a type of generator in which coils whose planes are parallel to those of the field magnet coils are swept past the poles, Fig. 120. In the first case the electromotive force is at a maximum for any conductor when it is directly opposite the pole; in the second case it is at a maximum when the armature coil is midway between two poles.

Generator Without Motion.—We are accustomed to think of

a dynamo or electric generator as a machine in rapid motion when active, and inert when at rest. But from what has been said it follows that it would be perfectly practicable to have a

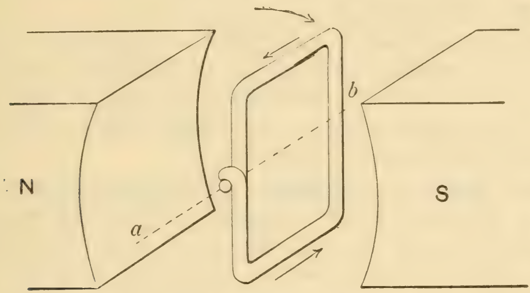


FIG. 119.—CLOSED LOOP IN A BIPOLAR FIELD.

dynamo without any moving parts if some way could be devised to change rapidly the intensity of the current passing through its field. A close analogue to such a dynamo is the alternating-current transformer. In it is a field of rapidly varying density with a conductor placed so as to have the lines of force pass through it. The changes in number of lines of force passing through it develop pulses of electromotive force so that an alternating current is produced.

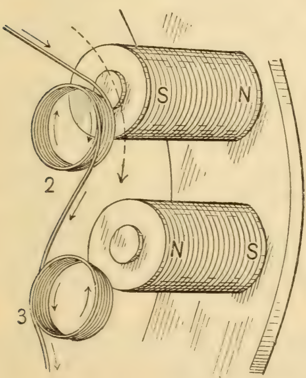


FIG. 120.—BOBBIN FIELD AND DISK ARMATURE COILS.

Examples of Induction.—If a telegraph wire or trolley wire were carrying a steady current and were set swinging by the wind, it would carry with it its field of force which would swing back and forth something like a huge cable. Theoretically there would be no limit to its diameter, but its intenser field would be within a limited radius from the conductor as an axis. This field swinging back and forth would sweep its lines of force across any

contiguous conductor, and if the ends of the latter were connected to each other or to the ground, would cause currents of brief duration to flow back and forth through it. Thus the trolley wire's every swing, however slight, produces some current through the rails below it.

The varying currents in a telegraph wire as Morse signals are sent through it make varying fields of force and set up pulses of electromotive force with consequent currents in contiguous conductors. The interference of telegraph signals with telephone circuits is a very familiar instance.

Telephone Receiver a Dynamo.—The telephone receiver can be used as a transmitter and originally was used as such. The minute vibrations of the thin plate which is supported close to the pole of a permanent magnet make the lines of force move about a little so that the coil of wire surrounding the end of the magnet is cut by varying numbers of lines of force. These variations induce electromotive force and currents, which reproduce in a distant telephone receiver the sounds of the voice. The telephone receiver used thus is really a dynamo. In actual telephone practice the microphone is used as a transmitter and induction does not play any direct part in its functions.

Laws of Induction.—There are several laws affecting electromagnetic induction which may be given here.

Faraday's Law is based on his discoveries in the induction of currents by the cutting of lines of force. It is given in the following words:

"When a conductor is moved in a magnetic field so as to cut the lines of force, there is an electromotive force impressed on the conductor, in a direction at right angles to the direction of the motion, and at right angles also to the direction of the lines of force."

Fleming's Rule for remembering this law and the connection between the three factors motion, magnetism, and induced electromotive force is this: Hold the thumb and first finger of the right hand at right angles to each other. Let the forefinger represent the lines of force and point in their direction. Then the hand will represent the north pole of a magnet. The thumb will represent the direction of movement of a conductor. The

latter is represented by the middle finger pointing at right angles to the other two. Then moving the conductor in the direction of the thumb, an electromotive force in the direction in which the finger points will be impressed upon it.

The words "current induced" may be substituted for "electromotive force impressed." When direction is attributed to electromotive force it refers to the direction of current which such electromotive force would produce.

The cut, Fig. 121, shows the relations of the three factors as described.

Ampere's Rule Adapted to Induction.—Suppose a man swimming along a conductor with his back to the north pole of a magnet whence lines of force issue. Then if he and the conductor together be moved toward his right hand, the induced current will flow in the direction in which he is swimming.

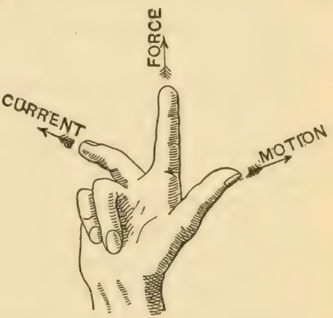


FIG. 121.—FLEMING'S RULE.

When the movement is not at right angles to the lines of force a certain proportion of the movement can be found which will be at right angles and this represents the effective portion of the movement. The object of the adoption of the idea of perpendicular movement is for the sake of simplicity.

Clerk Maxwell's Rule.—If a magnet is in the presence of an active circuit which therefore produces a field of force, each portion of the circuit acts upon the magnet in such a direction as would cause the magnet, were it free to move, to take up the position in which the greatest possible number of its lines of force would be embraced by the circuit.

Lenz's Law is a most convenient statement of the relations between the motions of magnetic poles and currents induced by their lines of force. While such relations can be worked out from a lower basis, the summarization known as Lenz's law will be found an admirable tool to work with. It is all-essential to

understand that it is in strict accord with Ampere's law. It is generalized by Daniell, author of "Daniell's Physics," thus: "Whenever a closed circuit capable of bearing an electric current lies wholly or in part in a magnetic or electro-magnetic field of force, any disturbance in the intensity of the field of force will induce a current in the circuit; and the direction of the induced current is determined by the rule that the new current will increase the already existing resistances (not electrical but mechanical resistance), or develop new resistance to that disturbance of the field which is the cause of induction."

The law is more briefly expressed thus: When a conductor is moving in a magnetic field a current is induced in the conductor in such a direction as by its mechanical action to oppose the motion.

It is also divided into two divisions, one for a generator reading thus: The induced current is always such that by virtue of its electro-magnetic effect it tends to stop the motion that generated it.

In accordance with this statement a dynamo requires more energy to be expended on it when it is generating current than when idle, because the passage of the current increases all electro-magnetic effects and also the Lenz effect of resistance to motion generating the effects.

For motors the converse division of the law is put thus: The motion produced in a motor by the passage of an electric current is always such that by virtue of the electro-magnetic inductions which it sets up it tends to stop the current.

This division covers the case of counter electromotive force.

Examples of the Application of Lenz's Law.—Synchronous alternating-current motors are addicted to varying in speed, going at one instant faster than the generator and at the next instant going slower. This action, disastrous to all regularity, is sometimes called hunting. It is checked by inserting coils of wire or other conductors in the field magnet pole faces. Currents are induced in these by change of velocity of the rotations. By Lenz's law such induced currents tend to stop the objectionable hunting motion which produced them.

A direct-current motor not doing anything and running with-

out any mechanical resistance ought, it would seem, to run at an indefinite and almost unlimited speed. As the motor turns it induces electro-magnetic effects, which are greater the faster it revolves. By Lenz's law these effects are such as to oppose its motion. As they increase with its speed, opposition to its motion increases with its speed. It cannot, therefore, exceed a certain rate.

This is another way of stating the action of counter electromotive force upon a motor.

Complaint is sometimes made that electric cars go too fast in cities. Their speed could be easily limited by constructing their motors so as to have any desired limit of velocity of rotation.

Two conductors carrying current in the same direction attract each other; in opposite directions, repel each other. If one wire is carrying no current but has its ends connected and the current through the other is increased, an opposite current will be induced in the second wire. The wires repel each other when current is induced, and in the opposite case, when induction is diminished, attract each other. Lenz's law fails to touch this case because there is no mechanical motion. But let a steady current pass through one wire and let the other closed circuit, which includes the second wire, be moved closer to it, and the current induced will resist the motion. It will be a current in the opposite direction. If separated the induction will resist the separation, and the currents will be similar in direction.

Lenz's law is best taken with its due limitations—that it only applies to the relations of electro-magnetic induction to mechanical motion causing it or produced by it. It is not a good practice to try to stretch it to cover induction where there is no mechanical motion.

Foucault or Eddy Currents.—If a conductor should be so moved in a field of force that the number of lines of force passing through it at an angle with its direction of motion vary, a current will be produced within it. This current will circle around in its mass, will absorb energy and expend it in heating the metal. Such currents are called Foucault or eddy currents. A set of infinitely thin conductors with ends unconnected moved through a field, if insulated from each other, would require the

expenditure of no energy, on the assumption that being of infinite thinness, no electric circuit can exist in them. If their ends were connected by a conductor under the conditions already specified as to variation in density of field, then a current would flow and energy would be absorbed. If a heavy solid conductor were substituted for the infinitely thin ones, while local currents would be established in it, there would be no through current all in one direction caused to pervade it. If its ends were connected by a conductor such a through current would be established. The local currents in the mass of the conductor are Foucault or eddy currents.

Variations in Impressed Electromotive Force.—The conductor which cuts the lines of force forms part of a circuit, and in

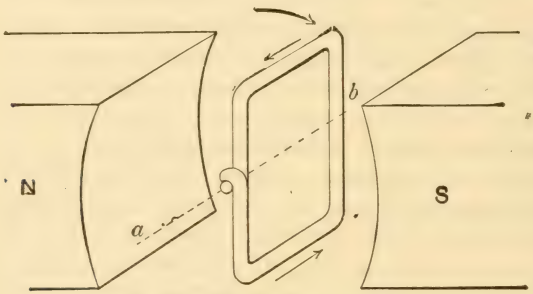


FIG. 122.—CLOSED LOOP IN A BIPOLAR FIELD.

cutting the lines of force either increases or diminishes the lines of force threading or interlinked with the circuit. The conductor indicated in the diagram, Fig. 118, starting at the left of the pole, cuts lines at a comparatively slow rate. This is because the lines are not so densely placed as directly opposite the pole. Hence a relatively small electromotive force is impressed upon it at the distant point. It cuts more and more lines of force in a second as it approaches the pole, thereby changing the number of interlinked lines with greater and greater rapidity, so that the electromotive force, and consequently the current, is strongest when the conductor is opposite the pole. It then, for like reasons, diminishes as the conductor recedes to one side of the pole in its motion. Such a conductor is shown in Fig. 122, reproduced

from a preceding page. There is another case the opposite of this. The conductor described is a part of a circuit the plane of whose moving portion is in line with the axis of the magnet when the armature conductor is opposite the center of the pole. Suppose the current is to be induced in a flat coil swept across the pole, and that the coil is perpendicular to the magnet axis when the coil faces the pole. Such coils are shown in Fig. 120

Such a coil will be interlinked with the greatest number of lines of force when opposite the pole, but its change rate will at that point be the lowest. The current induced by the impressed electromotive force will be least at this point.

This condition obtains in many alternating-current generators. The maximum electromotive force is induced when the armature coils are midway between two poles; the electromotive force is zero when the coils are opposite the poles and in the densest field.

Direction of Current Induced in Coils.—The direction of the current induced in a coil is determined by Lenz's law. If it approaches a north pole the currents induced will oppose its approach; they will therefore be the reverse of the Amperean currents or of the currents in the magnetic coils. As the coil recedes the currents will reverse also by Lenz's law so as to oppose the motion, and will coincide in direction with those of the magnet poles.

Fig. 120 and several other cuts illustrate the principle. The poles of a magnetic field are shown facing the observer; the direction of the induced currents is shown by the curved arrows. The coil in which current is being induced is moving in the direction indicated by the arrow. Arrowheads are marked on the coils to show the direction of the currents induced. When directly opposite the pole there will be no change in the number of lines of force passing through the coils, and no currents will be induced in them.

CHAPTER XI.

DIRECT-CURRENT GENERATORS AND MOTORS.

Dynamo - Electric Generators.—Electric energy is now almost universally produced on the large scale by dynamo-generators including the following parts:

A strong magnetic field or fields are produced by one or more electro-magnets. The magnetic circuits include the core of the electro-magnets and a mass of iron between or near their poles which constitutes the armature core. Coils of insulated copper wire are wound upon the armature cores. By mechanically changing the relations of armature windings and fields of force electromotive force is impressed upon the circuit and a current results. The product of electromotive force and current is electric power. Mechanical energy is required to operate the mechanism for changing field and armature coil relations. This energy is absorbed by the machine, and electric energy is produced in its stead.

The easiest way to understand the dynamo, as it is often termed, is to follow up the construction from the simpler to the more complicated types.

Interchangeability of Dynamo and Motor.—The interchangeability of dynamo and motor stands as the subject of one of the greatest discoveries in electric engineering. Electric motors had been constructed for many years before it was definitely decided that the same machine could receive electric energy and convert it into mechanical energy, thereby constituting itself a motor, or could be operated by a steam engine, water turbine, or other prime motor, receive mechanical energy, and convert it into electric energy. It then is a generator or dynamo.

As dynamos are calculated to give a definite electromotive force and current, and as motors are calculated to absorb a definite

electromotive force and current, the calculations for motor and dynamo are on the same lines.

Varieties of Dynamos.—There are two grand divisions of dynamos; one is for the production of the direct current, which is a current of unchanging direction; the other is for the production of the alternating current, which is a current reversing its direction periodically, in practice from twenty times upward a second.

Although a current which changes in direction may be considered as an aggregation of different currents of opposite direction, this aggregation is always called an alternating current, and is treated as a variety of single current.

The principal constituent parts of a dynamo are the field, consisting of core and winding; the armature, consisting also of core and windings; the collecting rings or commutator and brushes. The field and armature vary in construction, their windings vary in system, and from these variations many varieties of dynamos are derived.

Elementary Idea of an Alternating-Current Dynamo.—Assume a bipolar (two-pole) field which in the cut, Fig. 122, is indicated by two magnet poles facing each other and marked N and S. Let a simple rectangle of wire such as shown be rotated about an axis, *a b*, in such a field. As one side sweeps across the north pole the other sweeps across the south pole, and electromotive force of opposite polarity is impressed on the two sides of the rectangle, so that a current is produced through it. This current is strongest when the cutting conductors are passing the poles, sinks to zero or nothing when the plane of the rectangle is at right angles to the lines of force extending from pole to pole, and reverses in direction as this point is passed. During half the revolution the current flows in one direction, and during the other half in the other. This constitutes a dynamo.

Collecting or Slip Rings.—In this dynamo the current is confined to the rectangle, which is supposed to be a continuous conductor insulated from the axle. Suppose it to be cut at one end at the axle, and let the ends be connected each to its own ring fastened around the axle and insulated from it. The rings are also to be insulated from each other. If the rectangle is rotated, electromotive force of alternating polarity will be impressed

upon it, but as it is an open circuit, no current will be produced. Let a spring bear against each ring, and let a wire of greater or less length connect the springs. The circuit is thus closed, and currents first in one direction and then in the other flow through the whirling conductors and the wire. The rings are

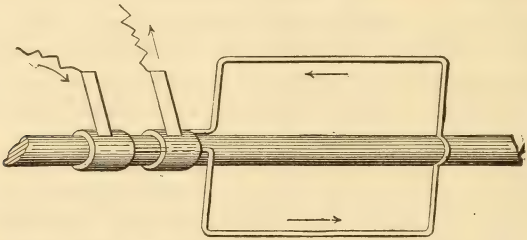


FIG. 123.—USE OF COLLECTING OR SLIP RINGS.

called collecting rings. The currents are treated as one and are called an alternating current. The arrangement is shown in Fig. 123.

Brushes.—The springs which bear upon the collecting rings or commutators are called brushes. Often instead of springs, blocks of carbon, pressed by springs, are used. The brushes must be insulated from the frame of the machine.

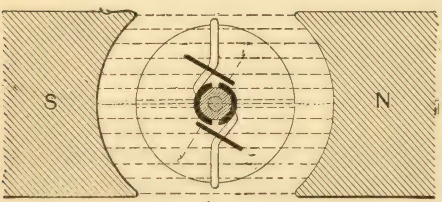


FIG. 124.—RECTANGLE CONNECTED TO COMMUTATOR.

Elementary Idea of a Direct-Current Dynamo.—In the next cut, Fig. 124, the rectangle is shown with its ends connected to segments of rings, each one as nearly as possible 180° or a half circumference in extent. They are insulated from each other and insulated from the shaft and attached to it. Springs at opposite sides press against them. The segments constitute a commutator, whose section is shown in Fig. 125. Let the rectangle in Fig. 124 with its two-part commutator be rotated in the

two-pole field. Let the springs which are insulated from each other be connected by a wire. As the rectangle passes the points where no current is generated, the springs pass from one commutator division to the other. As current goes in one direction through the rectangle, it is delivered to springs in one sense. As the current reverses in the rectangle, it is delivered to the springs in the other sense, because as the current changes, the springs change their contacts with the commutator segments. Hence the wire connecting the springs receives currents varying from zero intensity up to a maximum, but always in the same direction.

Increasing the Electromotive Force by Increasing the Turns.—The electromotive force is proportional to the lines of force cut per second by the whirling conductors. It may be increased

FIG. 125.—END VIEW OF TWO-PIECE COMMUTATOR.

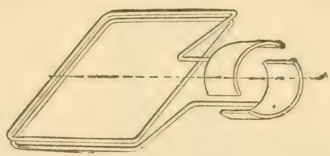


FIG. 126.—DOUBLE RECTANGLE CONNECTED TO TWO-PART COMMUTATOR.

by increasing the turns in the rectangle. In Fig. 126 they are shown doubled (the dotted line is the axis of rotation) and they may be increased any number of times. The turns are insulated from each other and are continuous. Doubling the turns doubles the electromotive force, and so on.

Increasing the Electromotive Force by Adding an Armature Core.—The field may be made denser by filling the space between the poles as completely as possible with a mass of iron. This is done by providing a cylindrical iron core, which almost fills the gap between them, and winding the wires on that. The denser field giving more lines of force, it follows that more lines of force are cut per second, and that a higher voltage results.

Armature and Core.—The iron cylinder with the wire windings constitutes an armature. The iron cylinder alone is the

armature core. The wires are the windings of the armature. Each convolution of the wire is called a turn.

Field Poles.—The early magnetos, dynamos, and motors were based on the horseshoe or U-shaped magnet as a producer of the field of force. Where a single magnet was used, this constituted a two-pole or bipolar construction.

Recent practice favors the use of more than two field poles, or of multi-polar dynamos. In these as a rule each pair of poles induces two parallel currents, and in typical winding there is a brush for each pole, and the brushes are spaced at equal angles around the commutator.

As a general rule, the number of poles is even; there are as many north poles as there are south poles. The poles alternate with each other, a north pole coming next to a south pole. Fig. 127 shows a section of a four-pole field with armature core, the lines of force being indicated by arrows.

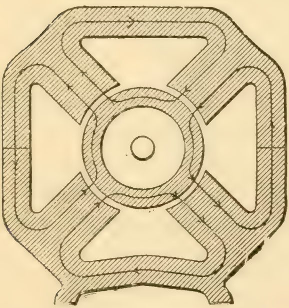


FIG. 127.—MULTIPOLAR FIELD AND ARMATURE CORE WITH MAGNETIC CIRCUITS INDICATED

Dynamos and motors can therefore be classified from their number of field poles as bipolar, four-pole, six-pole dynamos. Two general divisions are bipolar dynamos and multipolar dynamos, the latter including all except bipolar ones.

Open=Coil Armatures.—The elementary armatures described up to this are open-coil armatures. They may have any number of coils and any number of turns in each coil. Open-coil armatures are used in practice principally on the Brush and Thomson-Houston dynamos. In them they are greatly developed from anything shown here. They are used in great number on testing and signaling magnetos. The name open coil is given to them because no closed circuit can exist in their windings; the outer circuit has to be connected to the brushes to give a closed circuit.

Spindle or H Armature.—The spindle or H armature had in early days a considerable vogue. It is now definitely abandoned

in favor of better constructions, except for very minor uses. It is a single-division drum armature. The contour of the core is that of a cylinder with two grooves running lengthwise of its surface and diametrically opposite to each other. The cross section of such an armature represents a sort of letter H, whence one of its names was derived. It was a very distinctive armature with Werner Siemens in his early machines. It had a two-bar commutator and was an open coil.

It was a poor form, as it had low permeance and inevitably gave a highly pulsatory current, as it only admitted of two divisions in the commutator. The cut, Fig. 128, shows this armature.

Closed-Coil Direct-Current Armature.—This is a type whose windings are so connected as to form a closed circuit. This is irrespective of the brushes. The great majority of machines have this type of armature.

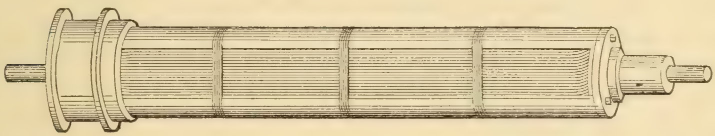


FIG. 128.—SIEMENS'S SPINDLE OR H ARMATURE.

The characteristic current distribution in a closed-coil direct-current armature involves parallel currents in its windings. In a two-pole dynamo the current in one half of the windings is parallel to that in the other. In a four-pole dynamo there are four divisions, each with its own current in parallel with that in the next division. The same principle applies to any number of poles. The collecting brushes are in typical constructions equal in number to the poles.

While the above is true for most dynamos, the windings of the armature can be greatly modified, so as to bring about different current distributions. The above are characteristic, and represent the usual practice.

It follows that the currents in a closed-coil direct-current armature never go through the winding consecutively. The brushes

are placed on the commutator at points where parallel currents meet. When the outer circuit is open, the electro-motive forces induced meet at these points and neutralize each other, so that no current is induced in the windings, although they are in closed circuit.

Cutting Lines of Force Without Change in Number of Interlinking Lines can also produce a current. The circular conductors which have just been illustrated as having no current produced in them, although they cut lines of force, have electromotive force impressed upon them. But the electromotive force can be located in halves of the ring separated by a diameter, in a general way perpendicular to their direction of motion. The electromotive force in one half is of similar polarity to that in the other half, so that they oppose each other and no current is produced. Electromotive force cannot exist without the possibility of a current being produced by it. A current by some mechanical arrangement could be taken from the extremities of the diameter of the ring without any change in number of interlinking lines of force. A machine in which this is done is called a homopolar, unipolar, or acyclic generator, and is described very briefly elsewhere. It has not gone into very extensive use, although it probably has a future.

The ordinary generator produces its effects by so cutting lines of force that the number interlinking the circuit changes as they are cut by the conductor. Without such change no current would be produced in ordinary machines. The point is mentioned here to fix the fact that the cutting of lines of force is what produces electromotive force, and that the variation in number of interlinking lines is something which happens in ordinary generators when the lines of force are cut. In homopolar dynamos the above variation does not occur. The cause of impressment of electromotive force is the cutting of lines of force, not the variation in interlinking lines of force.

CHAPTER XII.

DIRECT-CURRENT ARMATURE WINDING.

Armatures.—The function of an armature is to support conductors forming part of an electric circuit, which are to be subjected to the action of a field of force whose relation to the windings constantly varies. With fixed relations of the field to the armature conductors there would be no current induced in machines of the usual type as here described.

The relations are varied, so as to induce current by the sweeping of conductors and field poles past each other. This is universally done by having the poles and armature coils arranged on a circle; and by rotation of either armature or field, or by rotation of a series of "inductors" of soft iron past the poles, the desired varying of relations is brought about.

Armatures are wound in many ways. For direct-current work the closed-coil drum armature is much used. It is the successor of two historical inventions, the Pacinotti disk armature and the Gramme ring armature. In both of these the closed-coil feature appeared, which characterizes most modern dynamo and motor armatures.

The Pacinotti Armature.—The modern armature is with a few exceptions wound on principles exemplified by the famous Pacinotti (pronounced *Pacheenot-tee*) armature of 1864. These principles require the winding to be consecutive from beginning to end, so that the windings form one closed circuit. Such a winding is characterized as re-entrant when in the winding the last end falls into place, so as to be in line with the first end.

The winding is carried out as symmetrically as possible, and at symmetrical points it is connected to divisions of the commutator.

Pacinotti described his armature in 1864; it constituted part of

a motor. It was a disk-shaped armature mounted horizontally and wound with a continuous winding of wire and with sixteen connections from the windings to sixteen insulated bars on the axis of the disk, which bars constituted a commutator. Under the disk was a circle of iron polarized by an electro-magnet underneath it, and whose legs rose vertically to opposite extremities of a diameter of the iron ring. This produced two opposite poles on the ring.

There was here embodied the salient features of the modern dynamo, its continuous winding and commutator with numerous divisions, each connected to the winding. A toothed iron ring with wooden pegs or projecting pieces of boxwood formed the core on which the armature windings were made.

Pacinotti had no idea that by turning the armature mechanically a satisfactory current could be produced. His motor contained the elements of a dynamo unknown to himself.

The Gramme Ring, named from the inventor Gramme, was described in the Comptes Rendus (Paris) in 1871 and 1872. It was patented in 1870. It is a type of armature which acquired an immense vogue, and became in a sense one of the scientific glories of France. It is not much used in this country, where the drum armature is generally adopted. The Brush and Thomson-Houston open-coil dynamos are the principal American machines using it. But abroad many ring-armature machines are built.

Gramme's original ring core was made smooth and of circular cross section and was entirely overwound with wire.

Modern Types of Closed-Coil Armatures.—The modern armatures may be grouped into four classes: Ring armatures, drum armatures, pole armatures, and disk armatures. The ring armatures are based on the Gramme ring. The drum armature is sometimes taken as being derived from a Gramme ring by filling up the central opening with iron. The pole armature recalls an early type, and finds one of its great applications in alternating-current machines. The disk armature dates back to one of Pacinotti's machines.

In modern American practice the ring and disk armatures are not much used.

Armatures for direct current vary from those designed for al-

ternating current. The latter will be described by themselves. The ring armature may be taken as to a certain extent the prototype of the drum armature, and will be first treated.

The two-pole or bipolar dynamo is a little simpler than the multipolar one, and will be the starting point for the description of armature windings.

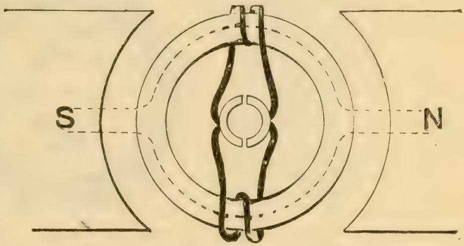


FIG. 129.—TWO-PART GRAMME RING ARMATURE.

The Gramme ring is a ring of soft iron on which the armature coils are wound. Fig. 129 shows in diagram a ring, supposed to rotate about an axis perpendicular to the paper in the two-pole field. The dotted lines show the course of the lines of force. The active parts of the armature windings are those on the outside of the ring. It may be made more complicated and efficient by doubling the parts, as in Fig. 130. B_1 and B_2 are the conductors from the brushes; at A and C no current is induced; at D and E the maximum is induced. The arrows give the course of the currents, and show how they meet in opposite commutator sections. The windings operate in parallel of two To make a real working armature, a large number of windings are requisite, and the commutator is divided into many subdivisions. Such a ring is indicated in diagram in Fig. 131.

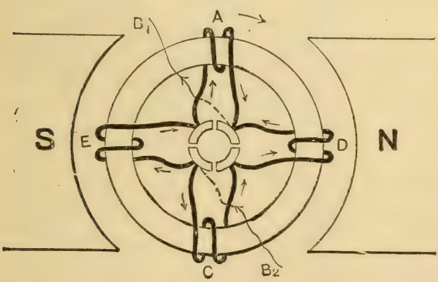


FIG. 130.—FOUR-PART GRAMME RING ARMATURE SHOWING COURSE OF CURRENT.

Commutator Connections of Ring Armature.—In practice a commutator is mounted on the shaft, and wires are led from the windings of the ring to it, and the brushes bear against the

commutator and take current from it. The wires are led from symmetrically or evenly spaced portions of the winding, and

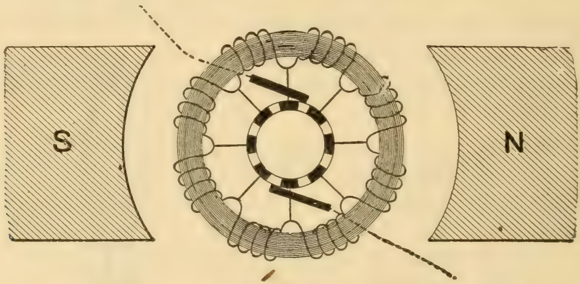


FIG. 131.—GRAMME RING ARMATURE SHOWING COMMUTATOR CONNECTIONS.

each one is connected to its own commutator segment or leaf. The commutator is used from mechanical considerations, otherwise the current could be taken from the conductors on the outside of the ring, as indicated in the diagram, Fig. 132.

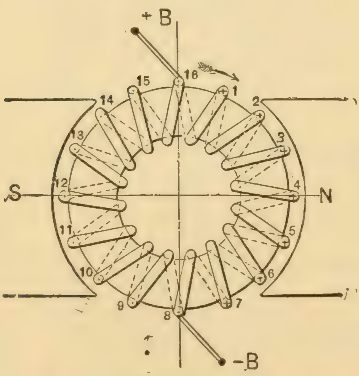


FIG. 132.—RELATION OF GRAMME RING TO COMMUTATOR BRUSHES.

Cores of Ring Armatures were originally made of iron wire wound into a circle of any desired thickness. Present practice makes them of thin ring-shaped laminations. A closed ring is somewhat troublesome to wind, so ring cores are often made in two semi-circular halves, over which the coils already made up can be thrust, after which the two halves are bolted together, so as to form a ring.

Permeance of the Ring Core.—One of the objections to the ring core for two-pole machines is its low permeance as compared with a drum core. Every effort may be made to reduce the central opening of the ring, yet it is

not easy to imagine a ring armature core of as high permeance for a bipolar field as a drum armature core would be.

The cross section of the core varies greatly with different constructors. The modern appreciation of the laws of the magnetic circuit has led to the production of ring cores of good permeance. Some of the older rings were thin, and consequently of low permeance. For multipolar machines a ring armature may have about as good permeance as that of a drum armature. This is on account of the course taken by the lines of force, which go into the core and out of it within a small portion of its circumference. In a multipolar machine they follow a U-shaped path from pole to pole, largely through the outer layers of the core. In the bipolar machine the lines of force have to go from one side of the ring to the other. This develops the bad permeance of the ring armature to the highest degree, as the lines of force following the curved path of the core have a longer distance to travel than that followed by them in going directly across a drum-armature core.

In plain ring winding there is a brush for each pole, which brushes normally collect current from points of the commutator nearly symmetrically located between the poles, so that a like difference of potential exists between each pair of contiguous brushes. By special winding one pair of brushes can be made to answer for a multipolar machine. This has the objection that it leads to unsymmetrical positions of the brushes, with consequent uneven voltage between the brushes appertaining to the two sides of the commutator.

Idle Wire.—In the ring armature the wire on the outside of the ring is the active portion. All on the inside is idle as far as the impressment of electro-motive force is concerned. This is one of the objections to this type, an objection which is of some moment, as low resistance in the armature is an element of efficiency.

Current in a Ring Armature.—The course of the currents in a ring armature in a bipolar field is shown in Fig. 133, in which the arrowheads show the direction. The currents meet at two points at the extremities of a diameter which is at right angles to the diameter determined by the axes of the poles. This axis is

marked A B. The arrowheads indicate the current in the eight coils. The impressment of electromotive force which causes the current is principally in the coils 2, 3, 6 and 7 of the armature in its present position, but the armature is supposed to be turning, so that the coils acted on are constantly different ones. The brushes remain fixed in position, indicated by the line A B. The arrows under N and S are supposed to be one in front of and the other behind the core, and indicate the current which will be impressed by the induction of the poles. The curved arrow denotes the direction of rotation of the core.

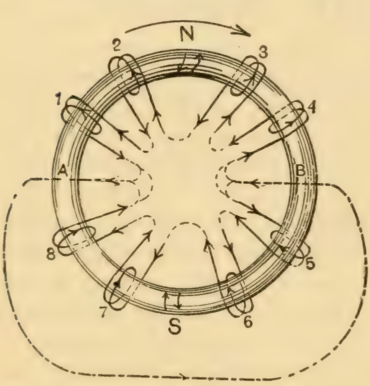


FIG. 133.—CURRENTS IN THE GRAMME RING ARMATURE.

Open - Wound Four - Part Ring Armature.—In Fig. 134 B_1 B_2 indicate the brushes which are taking current from the horizontally-placed pair of coils. These are in the position in which the highest degree of electromotive force is impressed upon them; and during the period of such active impressment, the brushes receive current from them. After a rotation of about half the arc of the commutator division, the coil is open-circuited, and the other one has its circuit closed, as the brushes come in contact with the commutator sections connected to it. This illustrates the principle of the open-coil armature. It apparently fails to utilize half the ring surface, but in any case one-half of this surface represents the locus of impressment of by far the greater part of the electromotive force. The arrows have the usual significance.

Mounting of a Ring Armature.—The diagram showing the relations of a ring armature to its field in a series-wound dynamo is shown in Fig. 135. The field magnet is wound to give consequent poles, N N and S S, above and below the vertical diameter of the ring R. The current is taken from the opposite sides

of the commutator and goes through the field coils. The axle A B of the armature is journaled in the magnet yokes.

Multipolar Ring Armature.—The ring armature can be used in a multipolar field without change. All that is necessary is to have more brushes than two, so as to take the current off from several parts of the winding. If the currents in a Gramme ring are traced, it will be found that neutral points are established equal in number to the poles of the field. If the winding and commutator connections are symmetrical, the neutral points will lie midway between the radii which go through the axes of the poles. The current is easily traced by following the rule given on page 210, and treating the parts of the wire outside the ring as conductors corresponding to the arrows of the diagram on the same page. It is in any case obvious that if the current is induced in one direction in front of the north pole, it will be induced in the other direction in front of the south pole. The currents therefore meet midway between the poles, and are to be taken thence by a brush. This brings a brush midway between each pair of poles, so that they aggregate one brush for each pole. The development of a four-pole ring winding is shown in Fig. 136.

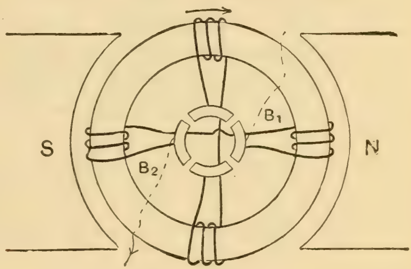


FIG. 134.—OPEN-COIL RING ARMATURE.

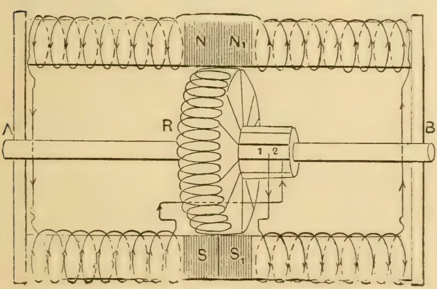


FIG. 135.—DIAGRAM OF WINDING OF A GRAMME RING SERIES MACHINE.

The Drum Armature.—It has been noted that the wire on

the outside of a ring armature is the active part. The large opening of the ring decreases its permeance. If the opening were filled with iron and the idle wire suppressed, one improvement would result—the lowering of reluctance or increasing of permeance, and in some cases there would also be brought about a reduction of resistance. If a reduction of resistance occurs, it is due to the reduction in length of the wire. This reduction is to be looked for in the transition from a thick ring core with small central aperture to the drum core—not in the transition

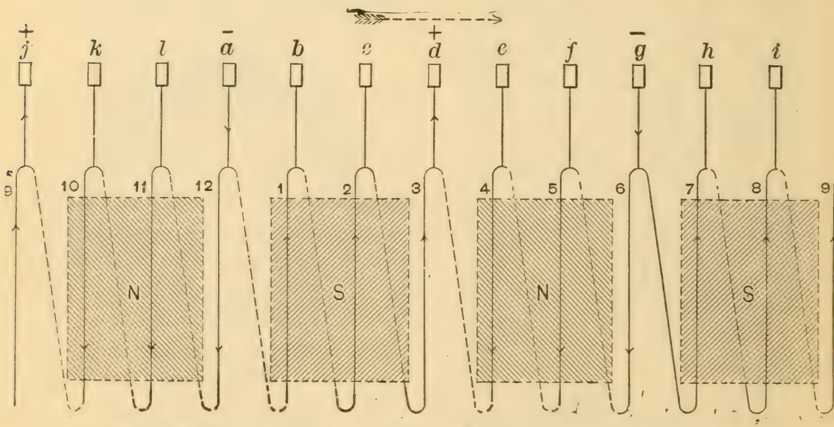


FIG. 133.—DEVELOPMENT OF A FOUR-POLE RING ARMATURE.

from the old-style thin-bodied ring core with large central aperture.

In the ring armature shown in Fig. 131 imagine the center opening filled with iron and the inner wires removed. Other leads must be carried across the two ends, so as to bring the whole quantity of wire into one consecutive coil, and from symmetrically-located points on the windings leads must be carried to a commutator. This gives a drum armature.

A drum armature is unlike a ring armature in one respect. If wound for a bipolar field, it will not operate properly in a four-pole or other multipolar machine. In a six-pole field it would give some result; in a four-pole field, none.

Action of the Drum Armature.—A conductor on the periphery of a drum armature swept across a field pole has impressed upon it electro-motive force the reverse of that impressed upon one swept past the opposite pole. If the current induced flows to the commutator end in one conductor, it will flow away from it in the opposite conductor. It follows that to obtain a continuous current such conductors should be connected to each other. Then the current as the circuit is completed will flow in one direction through one active wire, then across the end of the core in the connecting wire, in the reverse direction in the other active wire, and across the other end. If the wires correspond in angular distance to two opposite poles, this course of current will be given by the impressed electromotive force. This is the reason why wires opposite a north pole must be connected to wires opposite a south pole.

If a wire were connected to one directly opposite on both ends, there would simply be a series of short-circuited conductors, aggregating as many complete short circuits as there are leaves or bars in the commutator.

To secure a continuous winding, the conductors exactly opposite are not directly connected. Direct connection is made as described between conductors nearly but not quite opposite to each other. With every cross or end connection a step in advance (wave winding) or a step in retardation followed by a longer one in advance (lap winding) is made. The final result is the same in either case; a uniform progress around the cylinder is made by the windings, somewhat similar to a spiral.

Drum Armature Windings.—To form an idea as easily as possible of the essential features of the drum winding, an example may be given of a winding with very few conductors.

The winding of a drum armature may be divided into three classes or parts. The first are straight lines of wire or conductors which cut the lines of force. These lie upon the cylindrical surface of the core, parallel with its axis.

If we stop here, we have simply a lot of short straight pieces of insulated wire occupying the places of the elements of a cylinder. They are of the same length as the core. The commutator end of the armature may be termed its front end. The straight

conductors now must have their ends connected across the front and rear ends of the core. The rule which must be followed for closed-coil winding is that each wire must be connected to one at an angular distance from it corresponding approximately to the interval between the nearest north and south poles. For two-pole fields such as are now being described this distance is approximately 180°. At the back of the armature, wires run across its surface connecting the conductors on the periphery of the drum or cylindrical core, subject to the rule just stated. These operate with the front connections to connect all the winding into one continuous circuit. At the front each of the wires lying on the cylindrical surface is connected to an armature bar. To the same bar is connected a wire connected to an opposite conductor, which is approximately 180° distant from the first one in a two-pole field. If it were a four-pole field, the angular distance would be approximately 90°.

Simple System of Armature Winding.—In a simple type of bipolar winding the rear end of a wire might connect with one which would be one wire out of perfect opposition. In front it would connect to a commutator bar. The same commutator bar would then connect to another wire nearly opposite, which would be near to the one with the rear connection. This if repeated would join all the wires into one continuous lead. The number of commutator bars would be equal to one-half of the peripheral surface wires.

Eight-Conductor Drum Armature.—Suppose there were eight surface conductors or wires. Starting with any desired wire, let them be numbered consecutively. As the most natural way, we may start with wire 1. In front it is connected to a commutator bar, which we may designate as *a*. From this commutator bar the second connection runs to wire 4. This is one less than half the wires. The rear end of wire 4 is connected across the rear of the core to wire 7. Now returning to the front or commutator end, wire 7 is connected to commutator bar *d*, and the second connection from commutator bar *d* goes to the front end of wire 2. Counting forward, this is one less than half the number of wires. The rear end of wire 2 connects with the rear end of wire 5. The front end of wire 5 connects through the commu-

tator bar *c* to wire 8, also an interval of one less than half the wires. The rear end of wire 8 connects to the rear end of wire 3, and the front end of wire 3 through the commutator bar *b* connects with wire 6. The rear end of wire 6 connects with the rear end of wire 1. This closes the circuit.

A winding table for the above is given here.

1 *a* 4 indicates that wire 1 connects through *a* to wire 4.

7 *d* 2 that wire 4 connects to wire 7, that wire 7 connects

5 *c* 8 through *d* to wire 2, and so on as explained.

3 *b* 6 above. The letters *a*, *b*, *c*, and *d* denote bars of the commutator.

Twelve=Conductor Bipolar Armature.—The winding of this is shown in the diagram, Fig. 137. The dotted lines indicate the wires crossing the distant end of the core, the full lines those crossing its front. Again a departure of one wire from 180° angular distance is adopted. Wire 1 connects in front with wire 8 and on the rear with wire 6. Wire 1 to wire 7 would be 180° angular distance, whence it is evident that the winding is based on a departure from 180° of an interval of one wire. The commutator sections should be six in number, and should connect to the centers of the set of conductors which cross its end of the core.

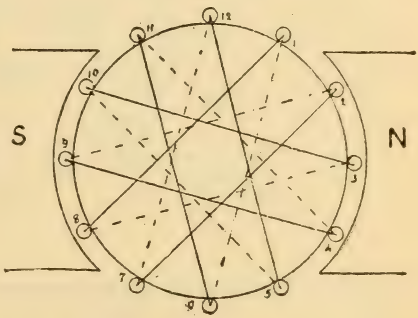


FIG. 137.—TWELVE-CONDUCTOR BIPOLAR DRUM ARMATURE WINDING.

Sixteen=Conductor Bipolar Armature.—The winding is shown on the basis of a departure of one wire from 180° in Fig. 138. The neutral line is shown at right angles to the polar axis of the field. On part of the circles representing the end view of the active conductors crosses are marked. These indicate that the current in those wires goes away from the observer. The circles with central points indicate that in the conductors they repre-

sent, the current is coming toward the observer. To remember this system, the points may be taken as indicating the points of arrows flying toward the observer and the crosses as indicating the feathers of arrows flying away from the observer. This system of indication is often used in textbooks.

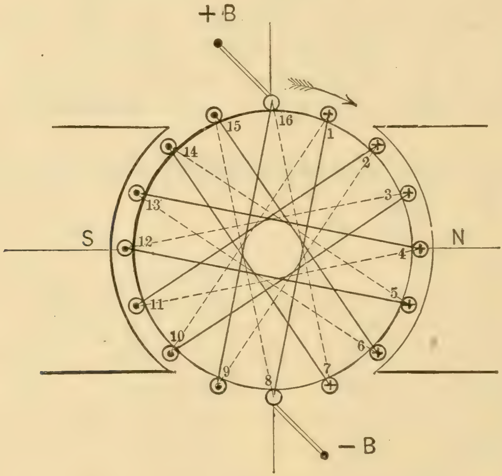


FIG. 138.—SIXTEEN-CONDENSER BIPOLAR DRUM ARMATURE WINDING.

Winding Tables.—The winding tables for these three armatures, omitting commutator bar letters, are as follows:

Eight-Conductor.			Twelve-Conductor.		Sixteen-Conductor.	
1	*a*	4	1	8	1	8
7	*d*	2	3	10	15	6
5	*c*	8	5	12	13	4
3	*b*	6	7	2	11	2
			9	4	9	16
			11	6	7	14
					5	12
					3	10

In the twelve-conductor winding, wire 6 connects with wire 1, and in the sixteen-conductor winding wire 10 connects with wire

1, thus making the windings re-entrant. The windings may be studied out on the cuts, when the full significance of the winding tables will be apparent.

Windings for Multipolar Fields.—In bipolar winding, everything in the way of the spacing of conductors is referred to 180°, or to one half of a circumference. The cross connections over the ends of the drum core connect conductors separated a little more or a little less than 180° from each other. The angular distance 180° is the distance from center of pole face to center of pole face.

When a drum armature is wound for a multipolar field, the angular distance between adjoining north and south poles is substituted for the 180° of bipolar winding.

Suppose that there are eighteen conductors on the cylindrical surface of the core. This gives four and a half conductors to each pole if there are four poles in the field. The quarter circumference is the controlling factor. Conductor 1 in bipolar winding might connect to number 12 or 14; in four-pole winding it may connect to number 6, number 6 to number 11, and so on, going five conductors at each connection.

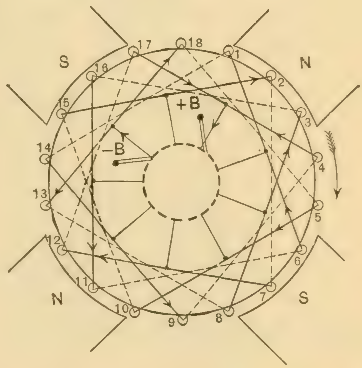


FIG. 139.—EIGHTEEN-CONDUCTOR FOUR-POLE DRUM ARMATURE, WAVE WINDING.

Eighteen-Conductor Four-Pole Armature.—This four-pole winding with eighteen conductors is illustrated in Fig. 139 in diagram as hitherto, and in Fig. 140 a circular development of the identical winding is given. The dark spots near the center of the latter diagram indicate the points where the brushes take the current. The outer lines forming the points of the star are the connections crossing the rear end of the core, and correspond to the dotted lines of Fig. 139. The short straight lines running from inner circle to outer circle represent the straight

conductors on the periphery of the drum. The cylindrical surface

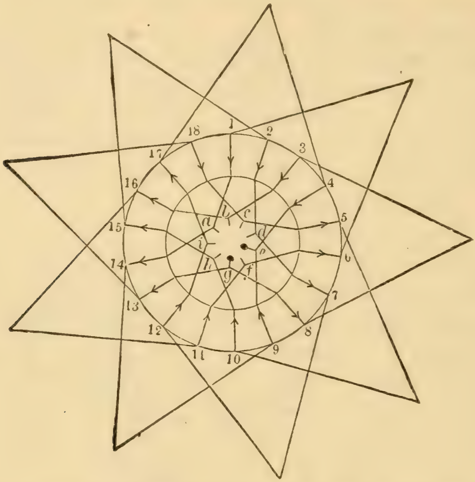


FIG. 140.—CIRCULAR DEVELOPMENT OF ARMATURE WINDING.

of the drum is represented by the annular area between the two circles. The lines within the inner circle represent the connections at the front or commutator end of the core.

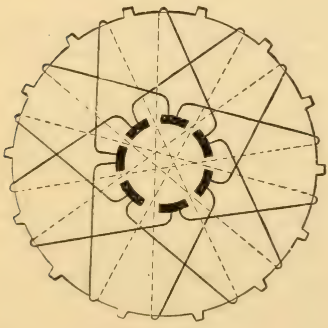


FIG. 141.—COMMUTATOR CONNECTIONS IN FOURTEEN-CONDUCTOR DRUM ARMATURE.

Circular Developments are used a great deal to illustrate armature windings. The points outside the rings have no real existence as shown. They merely indicate the center of the cross connections over the head of the armature core.

Commutator Connections are shown in Fig. 141, a fourteen-section armature winding with seven commutator divisions.

Wave and Lap Winding.—There are two divisions or classes of

winding for drum armatures, named as above. In the first a uniform progression is obtained in the winding; in the second a retrograde step of a definite number of conductors is followed by a forward step of a larger number. Thus in wave winding each step is progressive; in lap wave winding the sum of every two steps is progressive. The development of these windings most obviously shows the origin of their names. An example of the development of wave and lap winding for an armature with eighteen peripheral conductors will be shown.

Wave Winding.—The peripheral or active conductors are rep-

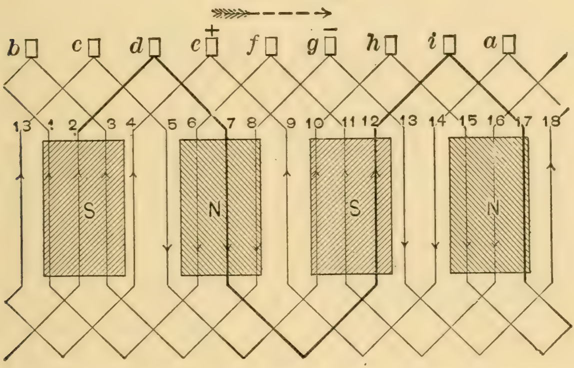


FIG. 142.—DEVELOPMENT OF EIGHTEEN-CONDUCTOR WAVE WINDING.

resented in Fig. 142 as vertical lines and numbered from 1 to 18. The cross connections at one end of the drum core are represented by the lines of V-shaped connections above the vertical lines; the cross connections at the other end of the core are represented by the V lines below the vertical lines. If the reader will follow the course of the wires with a pointer of any kind, he will see that there is a wave-like progress. The winding is exactly what is shown in Figs. 139 and 140.

Lap Winding.—The next cut, Fig. 143, shows the same armature with eighteen conductors as before, but with lap winding. Thus on the top of the diagram a wire starts from conductor 1 and goes to the right to conductor 6, which is five conductors

in progress. From conductor 6, instead of going forward the winding goes back on itself, or to the left to conductor 3; from conductor 3 the lead goes forward to conductor 8; then back to conductor 5, and so on. This ends by the winding from conductor 17 going forward to conductor 2 and back to conductor 1. This ends the winding and leaves it re-entrant. Thus the windings form a series of laps, going forward five sections and backward three sections, gaining two divisions for each two steps.

Development of Commutator Connections.—The commutator bars are shown in the development as little rectangles, and they

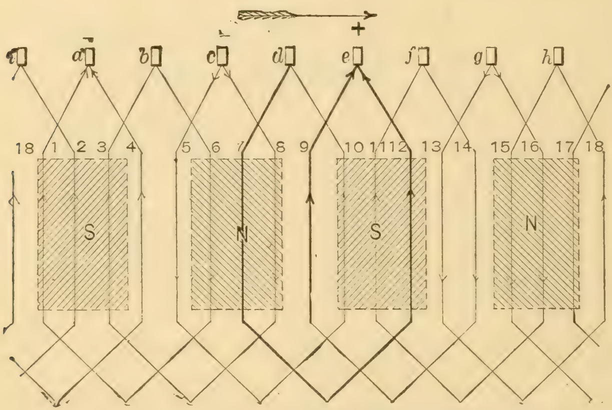


FIG. 143.—DEVELOPMENT OF EIGHTEEN-CONDUCTOR LAP WINDING.

are indicated by small letters. There is one bar for each pair of nearly opposite conductors, and in the development they are shown connected to the angles, either above or below the diagram. These angles in the development simply represent the centers of the end windings, which go across the ends of the drum; they do not necessarily represent any angle or bend in the wire.

Development of Field Poles.—These are represented back of the diagram, and each one is marked N or S according to its kind, whether north or south pole.

Development of Current Induced.—This is determined for

drum windings by the rule given on page 210, and the field poles in the diagram are shaded diagonally in accordance with that rule. If the conductors are carried from left to right, those in the range of the north pole will have downward currents induced in them, when the outer circuit is closed; those in the range of the south pole will have upward currents induced. Arrowheads are drawn to follow out this induction, and where the currents meet on the commutator, the brushes take off current to the outer circuit.

A twenty-four conductor four-pole lap winding is shown in Fig. 144.

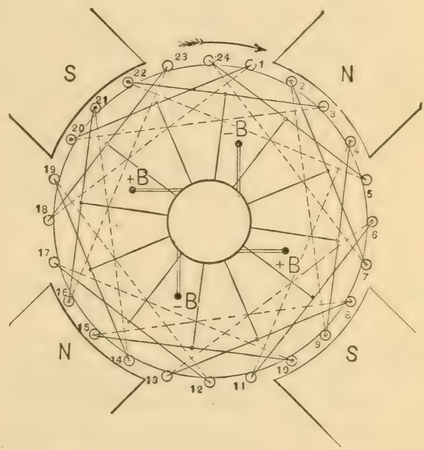


FIG. 144.—TWENTY-FOUR-CONDUCTOR, FOUR-POLE DRUM ARMATURE, LAP WINDING.

Straight Developments.—The cuts, Figs. 136, 142 and 143, show a system of development much used in illustrating armature windings. It is defective because it has disconnected ends. If the paper were bent into a cylinder, these disconnected ends would come together, and the winding would form a closed circuit or be reentrant. As drawn, this connection has to be assumed, just as the circular contour has to be assumed.

Winding a Drum Armature.—The drum armature winding in course of completion is shown in perspective diagram in Fig. 145. When completed a wire will pass around the cylindrical core in one continuous circuit. From symmetrical points leads are connected to the commutator bars. When such an armature rotates in a two-pole field of force, it will impress electromotive force upon a circuit connected to fixed brushes, two in number, bearing against the commutator surface at points 180° distant from each other and at approximately right angles to the diame-

ter connecting the center of the poles of the field magnet. The system may be followed out on the leads connected to the commutator bars, *d*, *e*, and *f*. The rest is incomplete, but the continuity of the winding is shown in the part mentioned. Some-

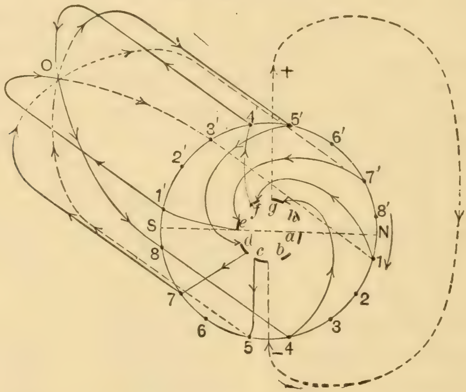


FIG. 145.—DRUM ARMATURE IN PROCESS OF WINDING.

times wooden pegs are driven into slots in the core to keep the winding in place while being put on, as shown in Fig. 146.

Another diagram illustrating drum armature winding is given in Fig. 147. The heavy black line represents one turn of the armature winding, fastened at one end to its proper commuta-

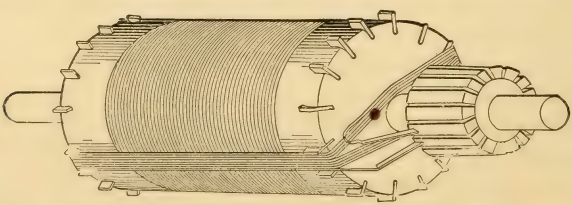


FIG. 146.—OPERATION OF WINDING A DRUM ARMATURE.

tor division. From the same division a second turn starts, and going around the drum connects to the next commutator division. The two diagrams illustrate the general lines on which drum armatures are wound.

General Considerations in Laying Out Drum Armature Windings for direct-current generation admit of no final description, because such windings can be executed in many different ways. A simple method of doing it, which follows the lines of what has been already described, is the following: The number of poles in the field must be known. Usually these are of even number and in pairs of north and south poles, the two alternating with each other. The number of layers of wire to be carried by the core is to be settled, and finally the number of commutator bars. The controlling factor in settling the last factor is the total voltage. This divided by the number of bars gives the voltage between adjacent bars. The lower this is kept, the less

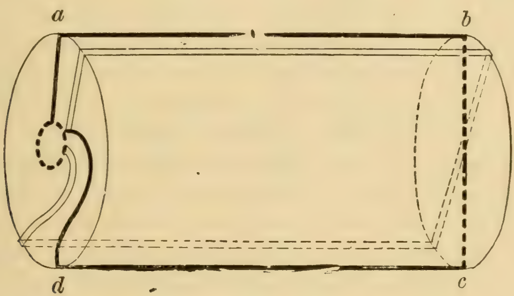


FIG. 147.—CONDUCTORS ON A DRUM ARMATURE.

danger will there be of sparking or arcing on the commutator. Another point to be kept in mind is that an increase of armature divisions, other things being equal, produces a more even electromotive force and current.

Single Layer Winding for Bipolar Field.—If the winding of the armature is based on single active conductors, there must be twice as many of them as there are bars in the commutator. But for each such conductor any number of leads of wire may be substituted. The windings, whether in one or several layers, must be divided into twice as many sections as there are divisions in the commutator. By section, as will be seen later, is meant a group of wires lying side by side on the armature periphery. Each such division forms a portion of a continuous

coil wound around the core along its periphery and over its ends.

Each such coil will leave two ends. These are connected each to its own commutator bar.

Suppose that there are to be thirty-two divisions in the commutator; there must then be at the least sixty-four active conductors on the cylindrical surface of the core. There may be substituted for a pair of single conductors connected across the ends of the core a coil of any number of wires, whose free ends are treated as are the ends of a single conductor in the simple case of sixty-four conductors. Suppose that there are two poles in the field. Then 180° is the controlling factor.

A circle is drawn to represent the end view or cross section of the cylindrical armature core. Around this circle representing the core section sixty-four points or little circles are drawn, evenly spaced from one another. These represent the end view of the sixty-four conductors or groups of conductors. The points or little circles are numbered consecutively. Starting from circle number 1, a full line is drawn across the large circle to circle number 32 or 34. Either one of these is one removed from the 180° position, which latter is held by conductor number 33. Suppose number 32 has been selected. From it a dotted line is drawn to number 63. This is also one less than 180°, being two points distant from point 1, and removed one point from 180°. Then from 63 draw a full line to a point removed by two points from point 32 and removed by one point from 180°. This is point 30. The same process is kept up until the line drawn from point 34 to point 1 closes the circuit, and makes the winding re-entrant.

Double-Layer Winding for Bipolar Field.—Suppose that there are sixty-four conductors as before, but arranged in two superimposed layers. The circumference of the circle is divided into thirty-two parts, and sixty-four points are distributed around it in two concentric circles, each containing thirty-two points. The inner circle of points is numbered from 1 to 32, and the outer circle of points from 33 to 64. Starting from number 1, a full line is drawn from it to number 16, and a dotted line from number 16 to number 31, and this is continued until all but one of the inner circle is connected and number 18 is

reached by a full line drawn from number 3. The inner circle of conductors could now be closed and made re-entrant by connecting number 18 to number 1. This is the only open portion left. But this would leave out the outer layer of conductors. Accordingly, number 18 is connected by a dotted line to number 33 on the outer layer. A full line connects number 33 to number 48, a dotted line connects number 48 to number 63, and eventually all is closed and made re-entrant by connecting number 50 to number 1 of the inner layer.

The object of drawing some lines dotted and others full is simply to distinguish between the ends of the core. The dotted lines cross one end, the full lines cross the other.

Commutator Connections.—Every cross connecting wire on one end of the core must be connected to a commutator bar. Taking the full lines for the crossings on the commutator end, each of these must connect to a commutator bar. If Figs. 143, 144, and others are referred to, the connection to commutator bars will be found indicated in them. The windings of the inner layer connect to alternate commutator bars, 16 in number; the windings of the outer layer connect to the remaining alternate bars.

Multipolar Windings.—These may be laid out by the method given for bipolar windings, except that the controlling angular distance is 90° instead of 180°. Suppose a thirty-two-section armature is to be connected for a four-pole field. The conductors are drawn as dots or little circles around a circle as before and numbered. Starting from number 1, it is connected to a conductor one less or one more than required for 90°, say to number 8, by a full line. Number 8 by a dotted line is connected to number 15, number 15 by a full line to number 22, and thus the process is kept up until a dotted line from number 26 to number 1 closes the armature and makes it re-entrant. This is a single-layer wave winding. Suppose that as before we had two layers, each of thirty-two conductors. Then when number 26 was reached on the inner layer, precisely as above, a dotted line would connect it to number 33, a full line would connect number 33 to number 40, and so on until number 58 would be reached by a full line from number 51; then a dotted line from number

58 to number 1 would close the winding and leave it re-entrant. The commutator connections are made substantially as described above.

Multipolar Lap Windings.—The last three examples progress evenly, and are therefore wave windings. To make them lap windings, conductor number 1 should connect with a conductor more than 90° distant, and this last conductor should go back in its connections toward number 1. Thus, taking a thirty-two-section four-pole winding, number 1 may connect by full line to number 10, this by dotted line to number 3, this by full line to number 12, and so on until the armature is closed by a dotted line from number 8 to number 1. This system makes the winding a lap winding whose net progression is two conductors instead of seven, as in the wave winding just described.

Variations on the above are innumerable. The controlling angular distance has here been taken as one conductor more or less than 180° or 90°. But other distances can be taken. The absolutely essential feature is that conductors directly connected must be acted on simultaneously by opposite poles.

Nomenclature for Drum Armature Windings.—A single turn of conductor comprising two peripheral conductors and the connections across the end of the core of a drum armature may have its front ends connected to two adjacent commutator bars. A coil of many turns of wire may occupy the same place, and have its front ends connected to two adjacent commutator bars. Either of these portions of a winding are called "elements." The active portions of an element lie on the cylindrical or peripheral portion of the core, one for one pole and the other for the other pole, and are called "sections." In connecting one "section" to another, so as to form an "element," a definite number of sections are bridged over or are caused to intervene between the sections of an element. A sixty-four-conductor winding under this nomenclature is a sixty-four-section or a thirty-two-element winding. In the sixty-four-section winding described on page 244 the distance from number 1 to number 32, which is a bridging of 32 — 1 or 31 sections, is called the "spacing," and it is a spacing of 31 sections.

General Formulas.—For a bipolar winding we start from one

of the ends of section 1. The cross wire is taken across the end of the core to a section a little more or a little less than 180° removed from it. If there are four poles in the field for 180°, there must be substituted 90°, if six poles 60° must be substituted, and so on. These controlling angles are equal to the quotient given by 360° divided by the number of poles in the field.

Taking a sixteen-section two-pole winding, it would have included 180°, had the cross wire gone from conductor 1 to conductor 9. Therefore, the wire may be taken to conductor 8 or conductor 10, one being 157°, the other 202° distant in angular measurement from conductor 1.

Bipolar Winding Formula.—Denoting the total number of conductors on the cylindrical surface of the armature by Z, and the number in one element by b, Z/b is equal to the number of elements in the winding; and the number of sections, being two in each element, is equal to $\frac{2Z}{b}$ and is denoted by s.

Let the spacing be denoted by y in the cases cited above. The general expression for spacing is

$$y = \frac{Z}{b} \pm a,$$

in which a is any number compatible with the requirements of re-entrant winding and the production of series connection through the winding.

For $\frac{Z}{b}$ in the last formula we may substitute $\frac{s}{2}$ because $s = \frac{2\,Z}{b}$, and therefore $\frac{s}{2} = \frac{Z}{b}$, and the formula becomes:

$$y = \frac{s}{2} \pm a.$$

Bipolar Winding by Formula.—To put a continuous re-entrant winding on a bipolar drum armature on these lines, s must be prime to y. If s and y have a common factor, the armature winding will have parallel re-entrant coils equal in number to this factor.

Thus assume $s = 16$, giving a sixteen-section winding with

eight armature bars. Let p represent the number of pairs of poles in the field. Let $a = 1$, and if the winding is bipolar, it follows that $p = 1$. $\frac{Z}{b}$ = half the sections or 8. In the equation $y = \frac{1}{p}\left(\frac{Z}{b}\right) \pm a$

By substituting for p and a their values, each being equal to one, and for $\frac{Z}{b}$ its value, or 8, we have:

$$y = 8 \pm 1 = 7 \text{ and } 9.$$

The one value of s which is 16 is prime to either of these values of y, so this winding will be re-entrant in one continuous coil.

The values $s = 16$ and $y = 6$ or 10, which would result from making $a = \pm 2$, are not prime to each other, because they have a common factor 2. It follows therefore that this spacing would give two re-entrant windings, parallel to each other.

Multipolar Winding by Formula.—There is no difference in general principles between bipolar and multipolar windings. Taking the four-pole winding described on page 245, the angular distance between sections is 78¾°, where in the sixteen-section bipolar winding the distance was 157 or 202½°.

The general formula just deduced can be made to apply to a winding for a multipolar field. Denote the number of pairs of poles, which is half the number of single poles, by p. Denote the spacing by y. The value of y is then given by the formula:

$$y = \frac{1}{p}\left(\frac{Z}{b}\right) \pm a = \frac{1}{p}\left(\frac{s}{2}\right) \pm a.$$

Suppose a four-pole armature with thirty-two sections. Then $p = 2$ and $s = 32$, and letting a equal 1, we have for the spacing:

$$y = \frac{1}{2}\left(\frac{32}{2}\right) \pm 1 = 7 \text{ or } 9.$$

The equation:

$$y = \frac{1}{p}\left(\frac{s}{2}\right) \pm a = \frac{s}{2\,p} \pm a$$

may be transformed to read:

$$s = 2\,p\,y \pm a.$$

This formula may be used to deduce the number of sections.

Assume that a four-pole winding is to have about sixteen sections; the spacing y will be about 16/4 or 4; and p, which is the number of pairs of poles, is 2. Substituting these values in the last equation, it becomes:

$$s = 2\ (2 \times 4) \pm 1 = 15 \text{ or } 17.$$

This method is only of interest for windings of many sections. For ordinary purposes a simpler plan is to take a number of sections divisible by the number of poles. Then select for the spacing a number one or two greater or less than one-quarter of the sections, remembering that it must be prime to the total number of sections, and without a common factor if for series winding.

Thus assume a four-pole armature; 24 is divisible by 4, and will answer for the total number of sections, s. We have then $s = 24$, $p = 2$, and $y = \dfrac{24}{2 \times 2} \pm a$. We may try for a the values 1 and 2. The formula then becomes $y = \dfrac{24}{2 \times 2} \pm 1$, or $\pm\ 2 = 4, 5, 7$, or 8. Of these, 5 and 7 are prime to 24, having no common factor. A spacing of 5 or 7 on a thirty-two four-pole winding will be in series and re-entrant. This winding with a spacing of 7 is described on page 245.

Lap Winding.—In bipolar and multipolar lap winding we have a net value for y. We have to go forward a distance equal approximately to the distance between the contiguous pole centers, and then to go back a lesser distance, leaving a net spacing equal to the difference between the two distances. This net spacing is equal to the algebraic sum or arithmetical difference of the two.

It is an object to have the commutator bars even in number. To do this the number of sections must be divisible by 4. Thus, a fourteen-section or eighteen-section winding would give a commutator of seven leaves or nine leaves.

CHAPTER XIII.

THE DIRECT-CURRENT GENERATOR.

The Magneto Generator.—This is a generator in which the field is produced by one or more permanent magnets. Fig. 148 shows a bipolar generator in diagram. Very large machines have been constructed with permanent magnets for the field. The cut, Fig. 149, shows the De Meritens machine, used for the production of the arc light, and the relation of field poles to armature coils is shown in the small diagram on the left, Fig. 150.

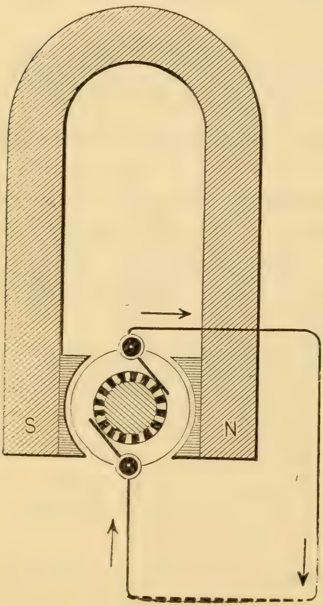


FIG. 148.—BIPOLAR MAGNETO GENERATOR.

The Modern Multipolar Dynamo has its yokes contained in and forming parts of a species of frame of iron. This is a circle or polygon. From its inner periphery cores, one for each pole, project toward the center like incomplete radii. The ends of the cores cut to the periphery of a smaller circle form or define the armature chamber or tube.

A drum or pole armature rotates in the space between the poles. One brush for each pole is typical. From these brushes one or more circuits may be supplied. The position of the drum, as it is acted on by the radial pulls of the symmetrically placed

cores, tends to hold a central position, which is correct. The virtually circular frame subjected to radial pull alone is exceedingly strong, and the magnetic pull cannot deform it.

There is no question of the material of the foundation, for nothing more than a magnet yoke, and perhaps not even that, comes in contact with the foundation.

To the mechanic's eye the symmetry of the multipolar machine is attractive. The projecting pole pieces are short and thick, so as to minimize leakage of lines of force. The rotating part of the machine, the commutator and the brushes, are at a distance from the floor, and less liable to pick up dirt than in the old type of machine.

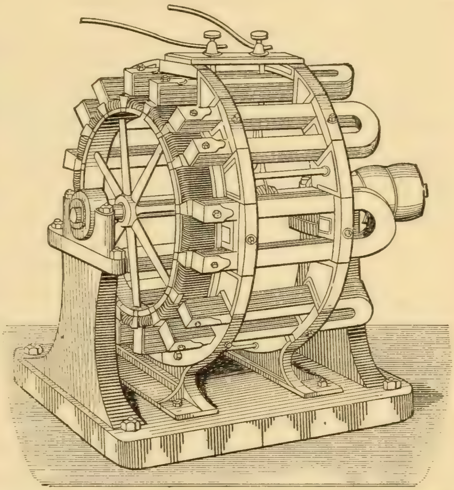


FIG. 149.—DEMERITENS MAGNETO GENERATOR.

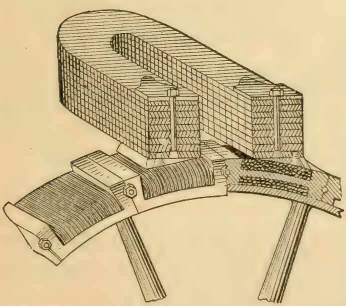


FIG. 150.—RELATION OF ARMATURE COILS AND FIELD.

The poles may be of any number, limited only by practical considerations. For direct current work relatively heavy currents as a rule are generated, so that the necessity of using thick wire tends to limit the number of poles.

The construction is symmetrical, and the field sections may be made on the interchangeable plan, even if some special planing is needed to bring them smoothly into place in setting up a machine. But the construction is so strong that there is never any need of replacing field sections.

Advantages of Multipolar Construction.—The old type of two-pole dynamo with parallel magnet legs has been abandoned generally for the multipolar type. The objections to the bipolar type are as follows:

To take the drag of the heavy armature off the bearings, the armature end of the magnet has to be placed downward. The magnetic pull tends to lift the armature from the bearings and make it run easily and prevent wear of the under journal-box. But the placing of the armature end downward makes it impossible to use an iron base for the machine. Such would short-circuit the lines of force, and would thereby weaken the field of force in which the armature rotates.

The long magnet legs give much magnetic leakage, as shown in Fig. 81, page 184, thus further weakening the field. Nevertheless, good results were reached with the old-time bipolar dynamos.

Field Winding of Dynamos.—The general principle upon which the field magnets of dynamos and motors are wound is exceedingly simple, and is what has been described under electro-magnets. Each pole piece has in the typical and almost universal class of machines to be of opposite polarity to its neighbor. The windings, if directly on the pole pieces, follow the rule of electro-magnet winding, so that the current around the south poles follows the direction of motion of the hands of a watch if the pole is facing the observer, and the reverse holds for the north pole. The windings in a bipolar magnet if on the legs compare exactly with those of an ordinary electro-magnet. The wire crosses from the front of one leg to the rear of the other, so as to give one north and one south pole.

A single winding on the yoke connecting the legs is sometimes used for both poles.

On multipolar machines with windings on the poles, the same rule is followed as for bipolar windings, the wire crossing from front to rear of the pole pieces adjacent to each other.

Series Winding.—The simplest or most natural conception of a dynamo is the series-wound dynamo. In it the terminals of the armature are connected as follows: One is connected to one end of the field winding. The other is connected to the end of the

outer circuit. The other end of the outer circuit is connected to the remaining field terminal. The cut, Fig. 151, shows a diagram of a bipolar series dynamo, and Fig. 152 shows the same in conventional diagram.

This type of connection is of almost historical interest. It is impossible not to recognize in it the foundation of the modern dynamo. The self-exciting dynamo, relatively small in size, had no difficulty in replacing the old magnetos. It must not be forgotten that powerful magnetos were constructed in old times, and were used for lighthouse illumination.

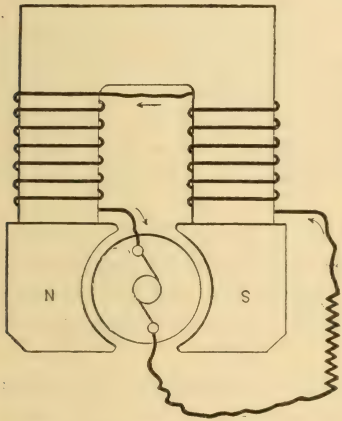


FIG. 151.—SERIES-WOUND DYNAMO.

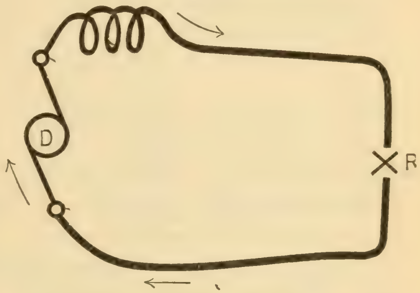


FIG. 152 —CONVENTIONAL REPRESENTATION OF A SERIES-WOUND DYNAMO.

But when the self-excited dynamo appeared on the scene, with a field enormously intensified over that of the old magneto, a veritable revolution was made. The modern engineer often winds his fields in parallel with the outer circuit, or has them wound with two coils part in parallel and part in series. He may use a small independent machine to excite the field, which also is an old idea, so that the principal machine has only its armature coils traversed by the current it produces. Yet the self-exciting series-wound dynamo must be regarded as one of the parents in the already long line of ancestors.

The winding is seen to be adapted to produce opposite polarity of adjacent poles.

Action of Series Winding.—The action of series winding brings about several conditions. The armature can generate no electromotive force until the field is excited by the current this electromotive force produces. Therefore to start it everything must be done to favor the production of current. The dynamo is best started on very low external resistance, and the armature may have to be speeded up. To facilitate starting, it is important to have good permeance, or to have a good magnetic circuit.

The polarity of the machine is fixed by the polarity of the field magnet poles. As shown in the cut, the direction of the current is indicated by the arrows. But if for any reason the dynamo began self-excitation or building-up with the north and south poles reversed, the current would flow in the other direction. This happens not infrequently with series-wound machines. For electric light this may or may not be of importance; for charging storage batteries or electro-plating it is imperative that no change occur.

If the resistance of the outer circuit is increased, the electromotive force diminishes. If the same resistance is diminished, the electromotive force increases. These two effects are due to the effect of resistance on the total current which passes through the field magnet coils.

If used for constant-current lighting, the addition of a lamp will cut down the electromotive force exactly when it is most needed. If used on parallel-circuit lighting, each new lamp lighted will cut down the external resistance, strengthen the field, and increase the electromotive force. This involves danger of burning out the lamps.

Series winding therefore has its defects, and the tendency is to adopt other windings.

Shunt Winding.—A shunt-wound dynamo is one whose field magnets are wound in parallel with the outer circuit. The terminals of the armature winding, which are the brushes, are connected each to two wires. One is a terminal of the outer circuit, the other a terminal of the field-magnet winding.

The cut, Fig. 153, shows a bipolar dynamo shunt-wound. Fig. 154 shows a conventional representation of the same. It will be seen that the potential difference or voltage expended in the

field magnet and outer circuit are identical. The energy expended on the field magnet is totally lost as far as any economic effect is concerned. It is of importance to keep its value as low as possible. The volts are fixed and beyond control. The only way of reducing the watts of energy expended in the field is to reduce the amperes. Accordingly, the winding of a shunt dynamo is of fine wire and of many turns. This causes it to carry only a small proportion of the total current. The watts absorbed by it, as the volts are relatively constant, is directly proportional to the amperes of current which pass through it. By this way of winding the field coils the proportion of energy expended on their excitation is kept as low as in the series-wound machines.

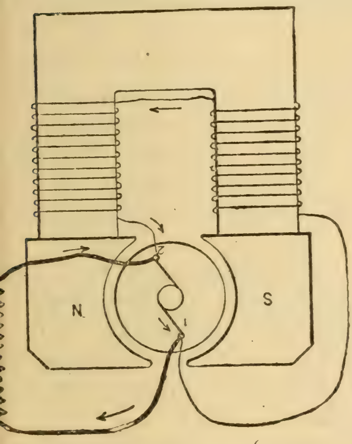


FIG. 153.—SHUNT WOUND.

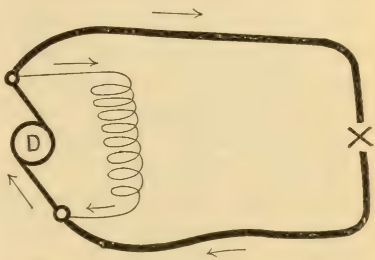


FIG. 154.—CONVENTIONAL REPRESENTATION OF SHUNT WINDING.

Action of Shunt Winding.—The action of a shunt-wound dynamo is the reverse of that of a series-wound one.

If the resistance of the outer circuit is increased, the field magnet receives more current, and the voltage at the armature terminals increases. The effect is that produced in the series machine by short-circuiting.

If a shunt-wound machine is supplying lamps operated in parallel, the resistance of its outer circuit will be decreased as more and more lamps are operated. This causes less current to be shunted into the field, and the voltage falls.

The effect of taking current from the field reduces its magnetization. This in its turn reduces the electromotive force generated by the armature. This reduction comes in as a third step, and again cuts down the field current. Nevertheless, some shunt dynamos with low-resistance armatures regulate themselves fairly well within a reasonable limit of action.

If the resistance of the outer circuit is raised, the intensity of magnetization is increased, as more current is shunted around the field.

A shunt-wound dynamo may supply a constant-current system of lamps very well. This is the system where the lamps are in series. If new lamps are added to the series, the resistance of the outer circuit is increased, more current is shunted through the field coils, and the electromotive force and voltage of the outer circuit increase. This is in the direction of meeting the greater demand for potential.

The series machine, because of its connection, must have the full current pass through its windings. This current cannot be changed. The current passing through the field windings in the shunt machine can be varied. This may be done by placing a variable resistance in circuit with the field windings. By increasing this the field is weakened and *vice versa*.

Compound Winding.—A dynamo consisting of a combination of the series and shunt machines is called a compound-wound dynamo.

The field magnet is encircled by two windings. One is a prolongation of the outer circuit, exactly as in the series dynamo. The other is a finer wire circuit, in parallel with the outer circuit, exactly as in the shunt-wound dynamo.

Of the compound-wound machines, there are two variations shown in the diagrammatic cuts, Figs. 155, 156, 157 and 158.

Short=Shunt Compound Winding.—The first variation, Figs. 155 and 157, is the short-shunt machine. The shunt field circuit is connected directly to the brush terminals. The outer circuit, with the series field circuit in series with it, is connected to the same terminals. The shunt field coil is in parallel with the line, containing outer circuit and series magnetizing or field coils.

Long=Shunt Compound Winding.—The second variation, Figs.

156 and 158, is the long-shunt machine. In this only one terminal of the shunt coil is connected directly to a brush terminal. The other end of the shunt coil connects to the outer circuit beyond the outer end of the series field coil. In this connection the shunt coil is in series with the armature and outer circuit and in parallel with the series coil.

Action of Short-Shunt and Long-Shunt Windings.—There is not much difference in the action of these two kinds of windings.

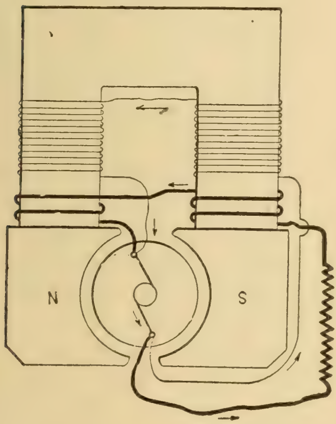


FIG. 155.—COMPOUND-WOUND DYNAMO, SHORT-SHUNT.

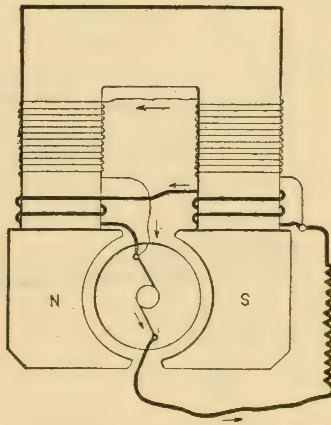


FIG. 156.—COMPOUND-WOUND DYNAMO, LONG-SHUNT.

In the short-shunt winding an identical current goes through the shunt as long as the same voltage is maintained at the armature terminals or brushes, because the shunt coil takes its current from those terminals. In the long-shunt winding there is a slight variation in the voltage of the shunt coil, with constant voltage at the brushes, if there are variations in the current in the outer circuit.

Self-Regulation of Compound-Wound Dynamos.—If a compound-wound dynamo is supplying a circuit at constant potential, it may be almost self-regulating. Suppose the resistance of the outer circuit to be diminished. This sends more cur-

rent through the series coil, and thereby acts to increase the intensity of the field. But the reduction of resistance in the outer circuit reduces the current in the shunt winding. This action goes to reduce the intensity of the field. By giving proper proportions to the two exciting coils, the intensity of the field can be kept practically constant as the resistance of the outer circuit is increased or diminished. The armature being kept at a constant speed of rotation in a constant field of force by the engine or other source of mechanical power, impresses on the circuit the identical electromotive force. As its resistance and that of the series field coil is constant, the voltage at the terminals remains constant.

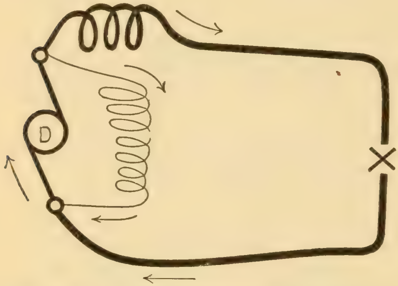


FIG. 157.—CONVENTIONAL REPRESENTATION OF SHORT-SHUNT DYNAMO.

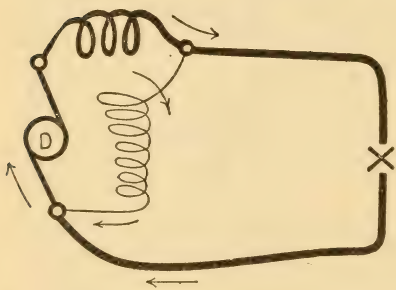


FIG. 158.—CONVENTIONAL REPRESENTATION OF LONG-SHUNT DYNAMO.

This applies to an accurately arranged winding. Whether the result is reached by calculation or by trial, it can be attained very closely. At high or low current strength there is apt to be a comparatively slight change in voltage.

Characteristic Curves.—On page 283 are given characteristic curves of series-wound and shunt dynamos. If it is realized that the characteristic of a compound-wound machine may be almost a horizontal line, its self-regulating powers will be seen. This appears from Figs. 176, 177 and 178.

Over-Compounding.—The result of such even action as described above is the maintenance of constant voltage at the terminals of the machine. In electrical work all sorts of conditions may have to be met. A very usual one is that on a circuit a constant voltage is required, not at the generating plant, but in the heart of the district, perhaps miles away.

In an over-compounded dynamo the series coil is given so many turns in proportion to the turns in the high resistance shunt coil that its influence overbalances that of the shunt coil.

The effect of over-compounding is to cause the voltage at the terminals of the machine to rise with increase of current. The proportional increase of voltage with increase of current can be accurately regulated by the relative sizes of the coils. It is only necessary to follow what has been said of the series dynamo, and to regard the compound-wound machine as a series dynamo greatly reduced in its characteristic action.

Over-compounding enables a constant voltage to be maintained in any point of a district. The resistance of the mains between the dynamo in the station and the given point in the district is known. The drop in voltage due to that resistance varies with the current. The over-compounding of the machine can be regulated to give the same increase in voltage with the increase of current, and thus the voltage at any desired point in the district can be kept constant, following Ohm's law.

Example of Compound Winding Calculation.—Suppose the resistance of a single lead of the mains to be 0.01 ohm. Then that of the two leads is 0.02 ohm. Suppose a maximum current of 500 amperes is needed. The drop due to the specified resistance and current is obtained by Ohm's law:

$$RI = E$$
$$\text{or } 0.2 \times 500 = 10.0 \text{ volts.}$$

This of course is an extreme case. But the dynamo by over-compounding can be made to vary its voltage at the terminals in this or any other desired proportion to the current. With the resistance given above, and the variation in voltage for the current as calculated above, which variation is at the terminals, a constant voltage would persist at the outer end of the leads.

Excitation of Field Coils in Compound Dynamos.—The series field coils of dynamos can only be excited by the working current or by a portion of it. If the machine is compound-wound, the series coils are taken care of by the machine. The shunt coils may receive their current from various sources. To make the machine self-regulating, it would seem that the shunt coil should be fed from the machine proper. This practice makes the dynamo self-contained.

Two other systems of shunt-coil excitation are used. In one system the terminals of the shunt coil are connected to the leads or bus-bars of the main circuit; in the other, a separate source of current is used for the shunt coils. When several dynamos are operated, and constant potential is maintained in the circuit at all times, a new element in the magnetization of the field is introduced because the magnetization, as far as the shunt coil is concerned, in this arrangement is independent of the speed of the dynamo. The excitation becomes zero when a self-exciting dynamo stops.

Effect of Independent Excitation of Shunt Coil.—If the terminals of the shunt coils are connected to an always active outer circuit, to station bus-bars for instance, the shunt coil excites the field as long as the connection is kept closed. As the dynamo runs slower the field excitation diminishes, but with less rapidity than before, and is never reduced to zero until the bus-bar or main circuit connection is broken. It is a case of under-compounding. The great advantage of it is that it makes it possible to excite the field before starting a dynamo. The field before the armature begins to rotate is not only excited, but the correct polarity is established. The instant the dynamo begins to work, electromotive force is impressed upon the armature coils, and there is no difficulty in bringing the voltage up to that of the main circuit.

Disconnecting or Opening the Shunt Coil.—The capacity of the shunt coil is considerable. It cannot with safety be disconnected by a simple opening of a switch. A bank of lamps is generally mounted in series with it. The field break switch is placed between the lamps and the main circuit. When it is opened, the resistance of the lamps prevents undue sparking.

Separate Excitation of Shunt Coil.—The shunt coil may also be excited by an independent source of electric energy. This may be a storage battery or an exciting dynamo. The separate excitation brings about a particular result. The exciting machine will be run at a constant voltage, so that the current passed through a separately excited shunt coil can be absolutely constant. The inevitable variations in voltage on the outer circuit bring about some variation in current in shunt coils fed from the bus-bars, which variation may be slight, but it exists. Otherwise, the result of separate excitation is not to be distinguished from outer circuit or bus-bar excitation. It gives another dynamo or storage battery to be looked after.

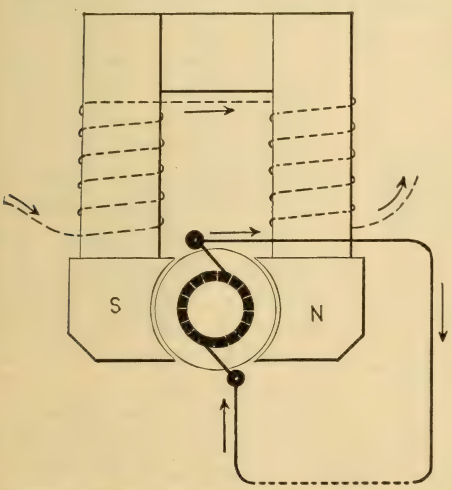


FIG. 159.—SEPARATELY-EXCITED DYNAMO.

Exciting Series Coils from Main Circuit.—A very obvious way of exciting the field coils of a compound dynamo is to send current through its series coils from the main circuit. This is done by closing two switches, one connecting a terminal of the field series-coil with one lead of the main circuit, and the other connecting the other end of the same coil with an equalizing bar or by special connection with the other main-circuit lead. This leaves the armature for the moment out of circuit. The dynamo can then be started and brought up to the proper potential. The armature has electromotive force impressed on it at once, and excites the shunt coil. Thus it is brought with certainty into action, and the polarity is fixed from the start.

Separately-Excited Generators.—The separately-excited dynamo closely approaches the magneto in its action, as the strength

of the field does not directly depend upon the current generated.

The diagram, Fig. 159*a*, shows the connections for the separately-excited machine. The field-magnet coils are entirely separated from the commutator connections. A current passing through the coils produces a field of definite and irreversible polarity. The armature rotates in the field, and impresses electromotive force of definite polarity on the circuit.

The current which excites the field magnet may be derived from a small dynamo, or from any source desired.

Action of the Separately-Excited Dynamo.—This arrangement has several advantages. The absolute irreversibility of polarity may be a very valuable feature. Thus, when storage batteries are being charged with a self-excited machine, the polarity sometimes becomes reversed. In such a case, if there is any charge in the battery, it discharges through the dynamo, and the latter becomes a motor, and the charge is wasted and lost. A similar trouble occurs in electroplating.

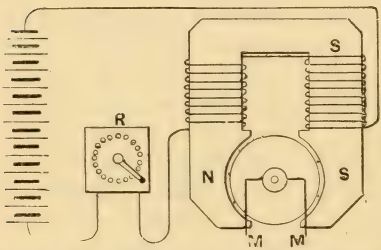


FIG. 159*a*.—RHEOSTAT FOR REGULATING SEPARATELY-EXCITED DYNAMO.

But with separately-excited machines this class of trouble is impossible. If its voltage is insufficient to fully charge a battery, it will at any rate not act as a motor and discharge what may be in the battery. The electroplater is certain that with a separately-excited dynamo his articles in the plating bath will receive the desired deposit and will not strip and lose what they have received.

Regulation of Separately-Excited Dynamos and Magnetos.—There are three general factors of regulation of magnetos and separately-excited generators.

The speed of rotation of the armature may be altered. This changes the lines of force cut in a given period. 10^8 lines of force cut per second, it will be remembered, gives one volt.

The brushes may be pushed forward on the commutator. This introduces demagnetizing turns in proportion to the advance of

the brushes. This is described in Chapter XIV. Thus the magnetic circuit, although produced by separate excitation, can be reduced by self-regulation.

Another way is to change the normal magnetic flux through the armature by outside means. An old device with magnetos was to provide a movable piece of iron, which could be moved toward or away from the poles of the magnet. This as it approached the poles shunted off more and more of the lines of force from

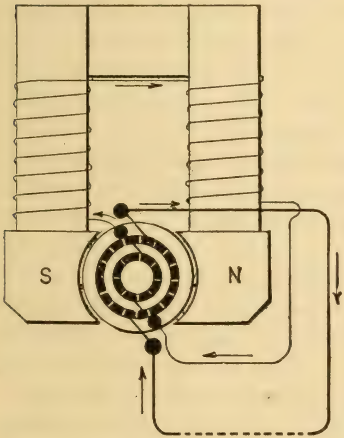


FIG. 160.—SEPARATE-CIRCUIT DYNAMO.

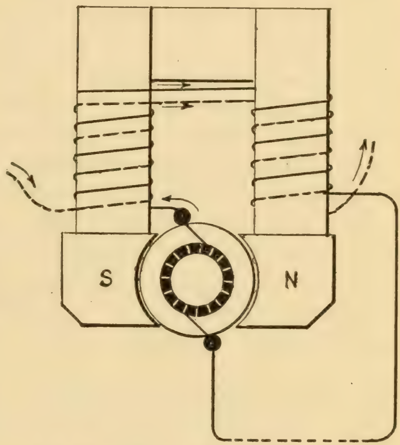


FIG. 161.—SEPARATELY AND SELF-EXCITING SERIES DYNAMO.

the armature, weakening the field and reducing the electromotive force. In separately-excited machines the current passing through the field-magnet coils can be weakened by the introduction of resistance into the exciting circuit, or by any other means. A rheostat-like arrangement can be introduced to cut out some of the coils of the field, as shown in Fig. 159*a*, in which R denotes the rheostat.

The Separate-Circuit Dynamo has either two separate armatures in the field space, or has two sets of coils. Whichever it is, one armature or coil set is used to excite the field, the other to supply the current to the circuit. Fig. 160 shows a

diagram of such a dynamo with two commutators, from one of which the field current, and from the other of which the field magnet current is taken.

Separately and Self-Excited Dynamo.—The diagram, Fig. 161, shows this machine, in which a current from an outside source passes through one field coil, and the main current of the dynamo passes through a second field coil.

Multipolar Dynamo Connections.—To avoid complication and to give diagrams readily understood, only two-pole machines have been illustrated in this chapter. But everything which has been shown for such machines applies to multipolar machines. The conventional diagrams may be used for multipolar machines exactly as employed in this chapter. The few turns of wire indicated may refer to the winding of any number of poles.

Conventional Representations of Machines.—The tendency of engineers is to simplify their diagrams as much as possible and to indicate a machine with numerous poles by a few lines only, as if it were of the simplest construction. Except for small machines the bipolar construction may be considered to be definitely abandoned, as is explained elsewhere. The brushes are conventionally drawn as if they were set tangentially. This is done for a purpose, as it serves to indicate the direction of rotation of a machine. Often this is not essential as far as the drawing is concerned, and the brushes may be shown as radial brushes or lines, as in Fig. 159*a*.

Later the representation of an alternating-current machine will be spoken of, and it will be seen that the distinction between the direct-current and alternating-current machine depends upon the representation of the brushes.

In these conventional figures those remain in use which are the simplest and most effective as regards freedom from misunderstanding.

CHAPTER XIV.

ARMATURE REACTIONS.

Armature Polarity Due to Its Windings.—The armature of a direct-current dynamo, by the polarity it acquires from its windings, modifies the course of the lines of force. If the dynamo is idle or on open circuit, no current passes through the armature, and any lines of force which may exist go straight across from field magnet poles to the armature core.

But the current which goes through the windings of a dynamo- or motor-armature operates to produce north and south poles in it. These are situated at points about equally distant from the poles of the field. In a bipolar machine the line connecting the north and south poles of the field is approximately or exactly at right angles to the line connecting the north and south poles of the armature core.

Action of Field Poles on Armature Core.—The field poles tend to induce polarity in the parts of the core nearest to them, the north pole inducing south polarity and the south pole north polarity. The effect of the combination of polarities, one due to the field poles' induction and the other to the induction of the armature windings, is to give resultant poles to the armature at intermediate points.

The lines of force emerge from one pole of the field, go obliquely to the opposite resultant pole of the armature, obliquely through the armature to its opposite corresponding pole, and thence obliquely to the adjacent pole of the field.

Field Distortion.—This armature reaction introduces manifestly an element of complexity into the subject. It is no longer a simple set of straight lines of force which constitute the field, but an S-shaped volume of polarized ether, constituting a distorted field of force.

Armature Reaction Diagrams.—The reaction of the magnetized armature core is easily understood from an inspection of the diagrams.

The diagram, Fig. 162, shows an idle armature lying between two pole pieces of an active field magnet. The wires are indicated by circles. Those with crosses show the current going away from the observer, those with dots the current approaching; those with neither show idle wire. The iron core of the arma-

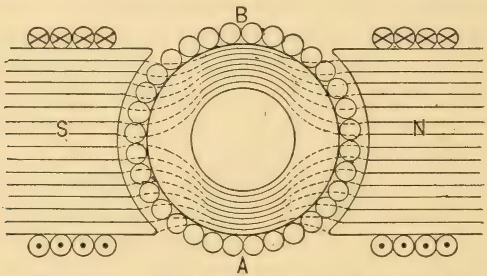


FIG. 162.—UNEXCITED ARMATURE IN EXCITED FIELD.

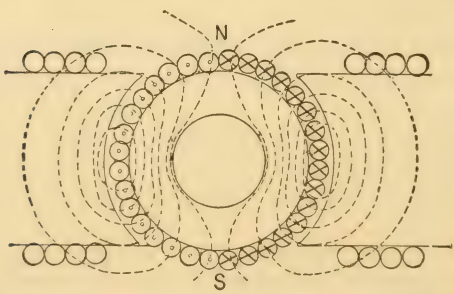


FIG. 163.—EXCITED ARMATURE IN UNEXCITED FIELD.

ture has induced in it two poles opposite those of the field mag net, and the general course of the lines of force is indicated by dotted lines.

The diagram, Fig. 163, shows an excited armature between the poles of an idle field. There the poles in the armature lie at

right angles to the field pole pieces, and the same conventional signs are used for the currents in the wires. The armature poles in this figure are at N and S.

In Fig. 164 both field and armature windings are supposed to be passing current. It will be seen that there are four poles, two N poles and two S poles, each pair at right angles to the other. The S pole of the field tends to establish an N pole in the armature core opposite to itself. The N pole of the field tends to establish an opposite and corresponding S pole in the armature core. The windings of the armature tend to produce their own poles on the vertical line as shown. The resultant poles in the armature lie between the two pairs. The resultant N pole lies

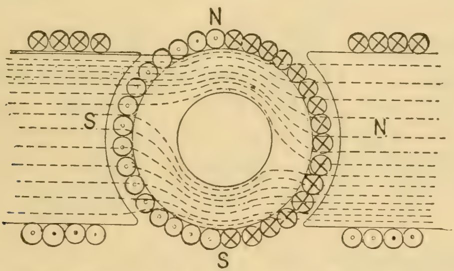


FIG. 164.—EXCITED ARMATURE IN EXCITED FIELD.

in the right-hand upper quadrant; the resultant S pole in the left-hand lower quadrant.

Varying Densities of Field.—Not only are the poles of the armature core thus displaced out of symmetry. The lines of force are densest in distribution between opposite-named poles of the field and armature core. They are crowded together toward the horns or ends of the pole pieces that lie in the direction of the motion of the armature. They are thinned out at the other horns. All this is shown in the cut. This crowding together of the lines of force is due to a reaction between the core poles and the field poles. This reaction in the case shown in the figure tends to displace the S field pole upward and the N field pole downward again in the direction of rotation.

Were there no displacement of poles, the poles of the armature

should lie upon a line at right angles with the line connecting N and S poles of the field. In the three figures these poles would lie on the vertical line. But owing to the armature reaction, the brushes have to be shifted in a dynamo in the direction of the rotation. Their line of position is now oblique to the line connecting the centers of the field magnet poles.

Neutral Points.—The points connected to the brushes are termed the neutral points. These normally lie at the ends of the oblique diameter described in the last paragraph.

It is perfectly evident that the armature reaction may vary under different conditions of load. Especially is this to be looked for in shunt or compound wound dynamos. The neutral points vary according to the relative intensities of magnetization of field magnets and armature cores.

Brush Adjustment.—To meet this variation of positions of the neutral points, the brushes are mounted on a rocker so as to be movable back and forth. They are rigidly connected with each other, so as to always be at opposite extremities of a diameter, but by turning their mounting or "rocker" back and forth, their position can be made to coincide with that of the neutral point.

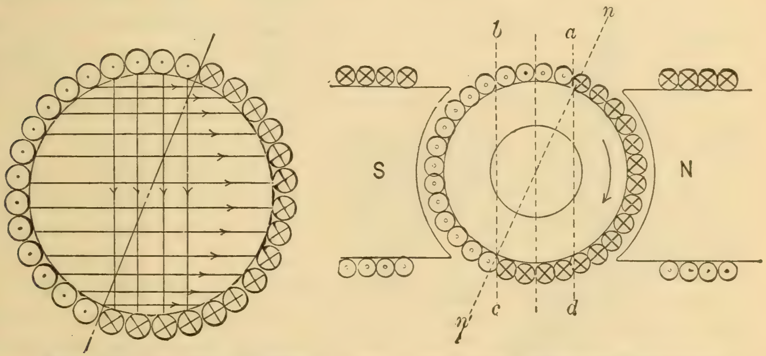
Demagnetizing Turns.—The brushes are advanced from the ends of the symmetrical line of the armature through a distance which may be stated in terms of an angle of so many degrees. If we go back from each brush against the direction of rotation a distance equal to twice this angle, we get a space called the demagnetizing belt, and the turns of wire comprised in this belt are called demagnetizing turns. In the cuts, Figs. 165 and 166, the condition is shown. *n n'* is the line connecting the neutral points; *a b* and *c d* cover the demagnetizing turns. The same conventional signs show the direction of current. It is obvious that the demagnetizing belt is working against the field-magnet turns, and reducing the intensity of the field of force. The brushes should be kept as near the symmetrical points as possible. The arrows in Fig. 165 show the general direction of the armature currents.

Reduction of Field Density.—Referring to the same figures, the turns outside the demagnetizing belt tend to diminish slightly

the intensity of field. This is by their action in crowding together the lines of force at the advanced horns of the field magnet poles. This reduces the permeability of the iron at that point, and hence reduces the field density or intensity.

Demagnetizing turns are entirely distinct from the armature reactions described on the preceding pages. The turns in the demagnetizing belt are in direction of current the reverse of those in the field magnet.

Action of the Demagnetizing Turns.—The action of the de-



FIGS. 165 AND 166.—NEUTRAL LINE AND DEMAGNETIZING TURNS OF ARMATURE.

magnetizing turns is to weaken the field. The armature core is a part of the magnetic circuit, and whatever affects the lines of force which go through it affects the whole circuit. The demagnetizing coils have no action except when a current is going through them, and their action varies with the intensity of the current. It is simply a matter of ampere turns working in opposition to the ampere turns of the field.

The electromotive force of dynamos naturally rises as the speed increases. But most series-wound machines reach a maximum. and then tend to fall off in electromotive force. It is due in great part to the advance of the brushes under increased load. This throws more turns of wire into the demagnetizing turns, and thereby increases the counter or back ampere turns. The distortion of the lines of force has also something to do with this.

Dead Turns.—It follows from the above and from some other reactions which may be included, that the increase in electromotive force is not strictly proportional to the speed. Thus, if the electromotive force were to be increased ten per cent, it might be necessary to increase the revolutions twelve per cent. The extra revolutions of the armature required, above the proportion of the voltage gained, are called "dead turns."

Spurious Resistance.—Self-induction in a conductor does two things. It resists the starting of a new current through a conductor, and tends to prolong the passage of an existing current if anything occurs to diminish it. The latter action is what produces the spark on opening the circuit of a spark coil. Consulting Fig. 167, it will be seen that one coil of an armature is shown short-circuited by one of the brushes. As the armature rotates, coil after coil is thus short-circuited. T and U have just been short-circuited, and W and X will next be. The self-induction acts to send a current through the coil for perhaps only a portion of the exceedingly brief period when it is short-circuited. This is a loss of energy. As it passes on, a new current has to be started, and is resisted by its self-induction. This is another loss of energy. These actions increase in degree with the speed, and reduce the current. They act like resistance, and the term spurious resistance is applied to them. Spurious resistance increases with the speed of rotation.

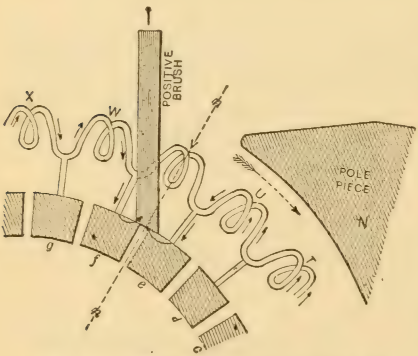


FIG. 167.—SHORT-CIRCUITING OF AN ARMATURE COIL BY A BRUSH.

Anything which will reduce the inductance of the armature will reduce spurious resistance. The fewer turns of wire in the armature, the less will the inductance and the spurious resistance be. But in designing dynamos and motors, spurious resistance is rather a minor consideration.

Eddy or Foucault Currents.—If electromotive force is impressed upon the windings of an armature, it follows that it will also be impressed upon all metal parts of it. The core is not only not exempt, but its periphery is subject to nearly as strong induction as the coils themselves. Accordingly, currents whose direction is determined by the regular laws of induction are produced in them. These currents existing within the mass of the metal are termed eddy currents or Foucault currents. The portions of the metal nearest the surface are most impressed with electromotive force; the outer portions cut more lines of force per revolution than do the inner portions of the core. The electromotive force impressed on one side of the core is of opposite polarity to that impressed on the other.

Differential action of electromotive force on a conductor will set up currents according to Ohm's law. These make themselves known by the heat which they produce in the metal in which they are generated. A copper or iron wheel rotated rapidly in a strong electric field becomes hot from the generation in it of eddy currents.

Eddy Currents in Armature Cores.—Energy is expended on the production of these currents, which is totally lost as far as any useful effect is concerned. There is no available way of suppressing them in armature cores except by a somewhat crude method. The core is built up of a quantity of pieces of thin iron, insulated from each other, and set at right angles to the direction in which the impressed electromotive force tends to produce a current. It is called a laminated core.

A cylindrical armature core is accordingly made of a pile of circular disks of thin iron. Between them are placed layers of some insulating material, such as paper, and thus the possible path of the currents is so much shortened that they amount in the aggregate to comparatively little. The object is thoroughly attained by making the disks as thin as possible and insulating them well.

Eddy Currents in Core Disks.—Eddy currents are established in core disks, though of relatively little importance. The cut, Fig. 168, shows how such currents act in laminations. The thickness of the lamination is greatly exaggerated in the cut.

Eddy Currents in Pole Pieces.—Any alteration in the distribution of the lines of force in the field will cause eddy currents in the contiguous masses of metal. Thus, eddy currents may be produced in the pole pieces of the field magnet if the iron core of the armature is not perfectly cylindrical. Some types of armature have projecting teeth of iron, the disks being out of contour to give projections. These teeth, as they sweep past the smooth circle of the pole pieces, virtually carry an intense little field of force of their own with them, and thus start eddy currents in the pole pieces.

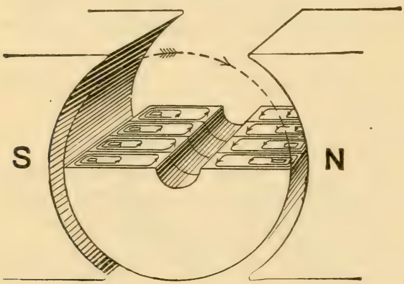


FIG. 168.—EDDY CURRENTS IN ARMATURE LAMINATIONS.

Every eddy current represents joules of energy, and has to be accounted for in the power.

End Leakage of Lines of Force in Armature.—Lines of force may leak around into the flat ends of the armature core. These will be enough to start currents flowing through these disks. If the armature core extends out beyond the pole pieces, this source of eddy currents is disposed of.

Eddy Currents in Conductors.—If the conductors or windings of an armature are very thick, eddy currents may be produced in them. This makes them carry several currents, one running counter in part of its course to the regular current.

All eddy currents, representing loss of power or waste of energy, must be suppressed as far as possible. The worst ones which can be produced are core currents, and these are minimized by laminating the core.

CHAPTER XV.

CHARACTERISTIC CURVES.

Characteristic Curves.—The action of dynamos under various conditions is represented by what are known as characteristic curves. These are diagrams constructed on the usual basis of lines at right angles to each other. The vertical line may be divided into parts representing volts—generally the difference of potential between the terminals of the dynamo. The horizontal line may be divided into parts representing amperes. The vertical and horizontal scales may also be given other meanings.

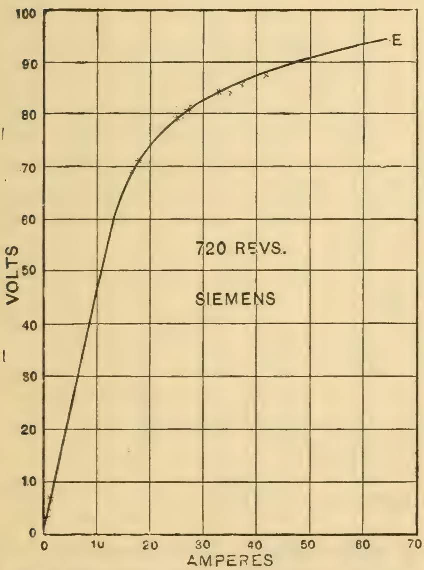


FIG. 169.—CHARACTERISTIC CURVE OF A SERIES-WOUND DYNAMO.

Hopkinson, who in 1879 first proposed this way of representing the action of a dynamo, used the values of the total electromotive force for the vertical line.

Fig. 169 is an example of a characteristic curve, E, of a series-wound dynamo. It shows the electromotive force for small currents increasing much more rapidly than it does when the current increases. It is evident that with enough current taken out of the machine, the electromotive force would remain practically constant.

The variations in current are produced with constant speed of rotation by changing the external resistance. The internal resistance remaining constant, and the field excitation varying with the current intensity, are two of the controlling factors which produce the curve.

Horse-Power Lines.—Seven hundred and forty-six watts or volt-amperes are an electrical horse-power. Points on a charac-

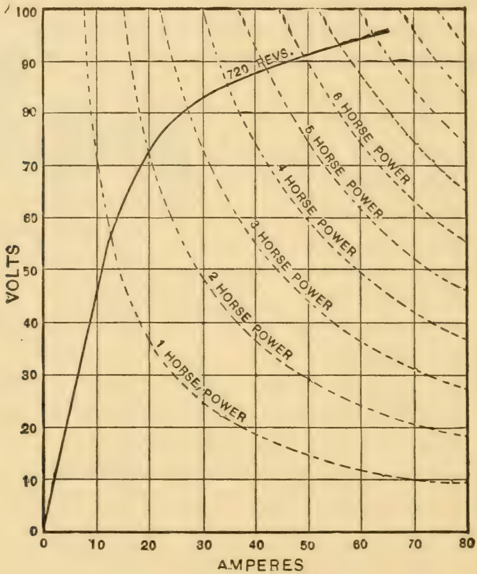


FIG. 170.—HORSE-POWER LINES.

teristic curve diagram can be determined where the product of the volts and amperes is equal to 746. These points joined give a one-horse-power curve. Other points are where the product of the volts and amperes is equal to 746 × 2 or 1492 watts, which are equal to two horse-powers. These points connected give a two-horse-power curve. The process is carried out for other horse-powers, as shown in Fig. 170.

The characteristic curve in connection with this set of horse-

power curves tells two things. It indicates the relation of amperes to volts in a specific machine corresponding to the various horse-powers.

Types of Characteristic Curves.—There are different types of characteristic curves. The one just spoken of is referred to the electromotive force of the dynamo, and is called a total characteristic curve. Another type of curve is referred to the potential difference existing between the terminals of the dynamo. This potential is easily determined by a voltmeter. Such a curve is called an e x t e r n a l characteristic curve, or sometimes the terminal-potential curve.

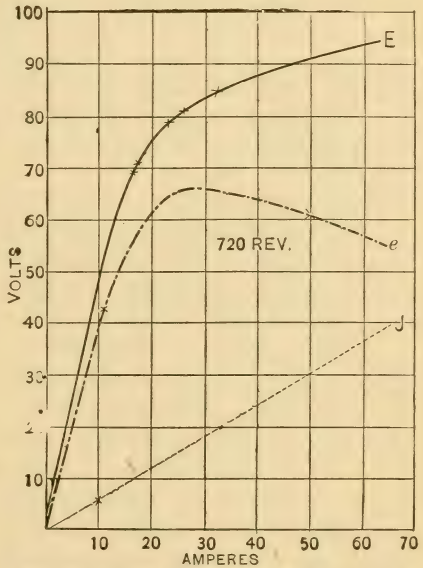


Fig. 171.—Total and External Characteristic Curves of a Series Dynamo.

Drooping Characteristic.—In the cut, Fig. 171, the internal characteristic curve, *e*, corresponding to the external one, E, is shown in dotted lines. Beyond a certain point, about 27 amperes, the voltage begins to decrease in value. A curve of such a shape is called a drooping curve. Sometimes characteristics droop much more than this. An advantage attaches to this drooping. It indicates that, should the machine be short-circuited while running, the electromotive force will not increase. A machine with drooping characteristic is advantageous for constant-current arc lighting.

The straight line J is the characteristic of the armature. The curve *e* is derived from E by subtracting the ordinates of J from those of E, and drawing the curve *e* through the points thus determined.

Interpretation of Characteristic Curves.—The resistance of a working dynamo and its circuit is made up of various components. The total characteristic gives the equivalent in ohmic resistance of true and spurious resistance under different conditions. By Ohm's law resistance is equal to electromotive force divided by current, or $R = \frac{E}{I}$

In the characteristic curve diagram, E is given by the vertical distance (ordinate), I by the horizontal distance (abscissa). Dividing one by the other, we get resistance in ohms. Or drawing a line from the lower left-hand corner (origin) to any point on the curve, the tangent of the angle that line makes with the horizontal line will be proportional to the resistance at the point in question.

This gives another basis for interpretation. If resistance is increased, the line making with the horizontal an angle whose tangent is equal to the resistance will swing back to the left, so as to increase the angle. This increasing of the angle will increase the tangent, which is as it should be, because the tangent represents resistance, which by the conditions assumed also increases. Such a line is called sometimes the vector line of watts.

As it approaches the vertical the tangent increases, and if the value of the current intensity, or of I, is kept constant, the value of the electromotive force or of E will increase. When the tangent of the angle becomes infinitely great, then an infinite electromotive force will be required to maintain a finite current.

Data for External Characteristic Curves.—When the voltmeter and ammeter have been used to determine the relations of current and electromotive force in a dynamo under different outputs, the data are obtained for characteristic curves. Here an important distinction is to be drawn. The voltmeter gives the potential difference existing on the outer circuit only. The amperes given by the ammeter are those which pass through the whole circuit.

Data for Total Characteristic Curves—This is a distinction which often has to be made. Amperes are identical over all parts of a circuit. Volts vary in proportion to the relative resistances of the parts of the circuit affected. If, having obtained the data

for an external characteristic, the electromotive force of the whole circuit can be substituted for the potential difference given by the voltmeter, the new data will give the total characteristic.

The resistance of the dynamo being known, Ohm's law gives the electromotive force of the system. Suppose a current of 50 amperes is taken on the external characteristic, the dotted line curve *e*, Fig. 171; this gives 60 volts. By Ohm's law the external resistance is equal to $\frac{E}{I}$ or $\frac{60}{50} = 1.2$ ohms. The internal resistance of the particular dynamo tested was 0.6 ohm. The total resistance of the circuit was therefore $1.2 + 0.6 = 1.8$ ohms. The electromotive force of the whole circuit at 50 amperes of current is now deduced by Ohm's law: $E = R\,I = 1.8 \times 50 = 90$ volts.

Drawing Characteristic Curves.—In the ways above described a number of points on a characteristic curve are found, and from these the curve is constructed. For each value of current strength a value of voltage as given by the voltmeter for an external characteristic is given, and a value of electromotive force calculated as above for the total characteristic is also given.

These points are marked upon a sheet of paper. The current measurements are taken on horizontal lines, the voltage and electromotive force measurements on vertical lines. The curve is then drawn through these points. A thin flexible strip of wood called a spline is a simple appliance for such purposes. A more efficient instrument is the flexible ruler. Its construction is based on the use of a bar of lead. This is bent to any desired curve, and holds its shape. The splines spring back when released.

The easier characteristic to get is the external. It has to precede the total characteristic. Its data are absolute and useful. The data of the total calculated as described leave armature reactions out of account. When a characteristic is given and no statement is made that it is a total characteristic, it may be taken as an external one. It is bad practice not to state whether a characteristic is external or total.

Internal Characteristic.—It is obvious that there is an internal characteristic. This is based on unvarying resistance. It is therefore a straight line.

We may prove this by returning to the radius vector of watts. If resistance is constant, the tangents of all radius vectors of watts must be constant. This is equivalent to saying that all such radius vectors must coincide in direction. They will all be represented therefore by parts of one straight line. They will vary among themselves only in length measured from the lower left-hand corner (origin).

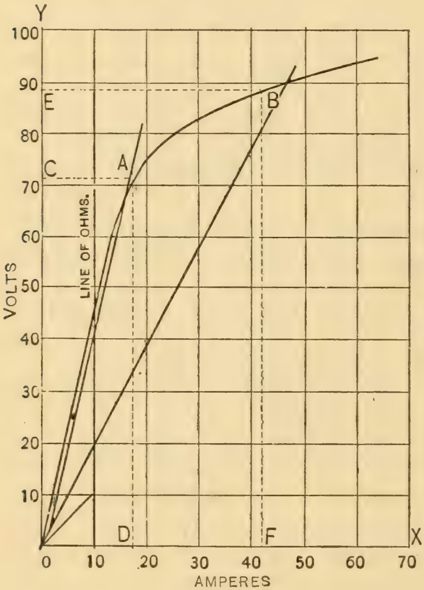


FIG. 172.—LINE OF OHMS IN CHARACTERISTIC CURVE DIAGRAM.

Terminology of Analytical Geometry.—The word given in parentheses is one of the terms used in analytical geometry. The vertical line on the left is the axis of Y or of ordinates; the lower horizontal line is the axis of X or of abscissas; horizontal lines are abscissas; vertical lines are ordinates; the intersection of the axes of X and Y is the origin.

Line of Ohms.—The diagram hitherto has not directly shown ohms. It is divided into squares. A diagonal to the lower left-hand square drawn from the origin will be an angle of 45° with the horizontal, and its tangent will be 1. This is taken as 1 ohm. The vertical line or ordinate through the right-hand end of this square is taken as the line of ohms. A radius vector of watts drawn to any part of the curve will have its tangent given by the part of this vertical line cut off. The value of this tangent will give the ohms resistance. In the diagram, Fig. 172, the resistance at the point B is 2 ohms, at A 4 ohms, and so on.

The line of ohms is erected on the point 10 of the base line.

The line from O to B is the radius vector of watts. It intersects the line of ohms at a distance 2 from the base, taking the side of a square as unity. This shows that at the point B the resistance is 2 ohms. As B corresponds to 90 volts and 45 amperes, by Ohm's law $R = \frac{E}{I} = \frac{90 \text{ volts}}{45 \text{ amperes}}$ or 2 ohms, which corresponds with the diagram.

On the same diagram the resistance line, or line of ohms, can be used for either internal or external characteristic. The intersection of the internal radius vector of watts with it will give the constant internal resistance.

General Notes on Characteristic Curves.—The changes of resistance are effected by the manipulation of the outer circuit by the observer. Resistance is thrown in and out as desired, in order to get the different points of the characteristic.

To give a characteristic any meaning, one of the factors must be kept constant. This is always the revolutions per minute. But a characteristic could be based on fixed resistance, and the changes in current and voltage could be brought about by varying the speed. Then the tangents of the radius vectors of the watts curve being equal as denoting the resistance, the curve would merge into a straight line.

Fixed current might be the basis. Then the characteristic would become a simple vertical line. Its position would give the amperage. Its length would give the voltage as long as the resistance was unchanged. If the resistance was increased, the radius vector would cut it higher up, and the voltage would be given by the place of intersection.

Fixed voltage as a basis would give a horizontal line, whose length would give the amperage. The intersection of the radius vector with this line determines the amperage corresponding to any desired resistance.

This makes it clear why characteristics are given with fixed speed of rotation. The straight lines do not give the peculiarities of a dynamo as fully as do the curves. By changing the speed, we virtually change one dynamo into another.

Critical Current.—A characteristic curve of a series dynamo starts as a nearly straight line. At its beginning its radius

vectors are virtually one except in length. At first doubling the voltage doubles the current approximately. But after a while the curve bends to the right. On examining Fig. 170, it will be seen that for a given increase in voltage, the amperage will increase more rapidly than before. The point where this change is noticeable is a sort of critical point. The current corresponding to it is called the critical current. It is obvious that there is nothing accurate about it. The critical current is the minimum current required to excite the field. With insufficient ampere turns, a field magnet will not produce an adequate intensity of field. Therefore with a series dynamo too high an external resistance, cutting down the current, will weaken the field. This weakening may be enough to arrest the dynamo in its functions, and cause it to give hardly any electromotive force. It may easily prevent it starting into action from inaction.

A series dynamo must be started on low external resistance, and the resistance must never be so high as to cut the current down below the critical value.

The electromotive force given by a dynamo increases with the speed. The resistance may accordingly be increased as the speed increases without affecting the current. Therefore there is no critical speed or critical resistance for a series dynamo, except in the most general sense on short circuit.

Shunt-Wound Dynamo Characteristics —There are three possible characteristics of this type of machine. One is the total characteristic, which includes the armature current and the electromotive force. The armature current is equal to the sum of the currents passing through the field winding and shunt winding. The second is the external characteristic. This is based on the voltage between terminals and the total current of the outer circuit. This current is a part only of the armature current. The third is the so-called internal characteristic. This is based on the same voltage as for the second case and on the amperes in the shunt or field magnet windings. Possibly some ingenious person might evolve a fourth and a fifth characteristic, taking the armature into cases two and three. In practice the external and internal characteristics are most used. These are the second and third of the preceding list.

Critical Point of Shunt-Wound Dynamo.—The external characteristic of a shunt-wound dynamo is given in Fig. 173. It begins at the top at P. On open circuit all the current is shunted into the field, and the voltage between terminals reaches its maximum. The resistance of the outer circuit when open is infinite. The outer circuit is now closed through a very high resistance. This shunts a certain amount of current from the field coil, and weakens the field so as to reduce the voltage. The resistance is gradually lowered, shunting more and more current from the field as more passes through the external circuit, until a sort of critical point is reached. This point is where a reduction of external resistance begins to rob the field of so much current that the electromotive force falls more rapidly than before. At this point the watts are at a maximum. At last the curve, at the 35-volt-32-ampere point in Fig. 173, reaches a point of instability, and with very little change of resistance runs down to a zero value.

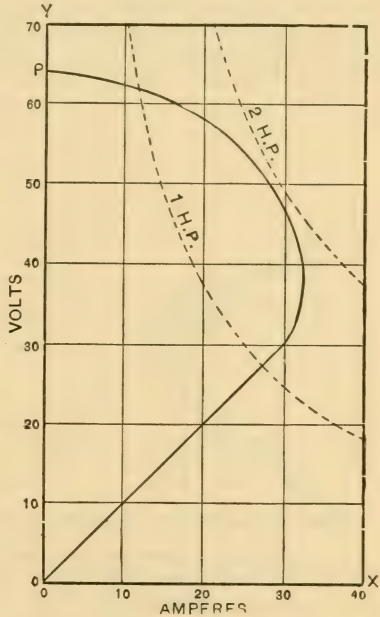


FIG. 173.—EXTERNAL CHARACTERISTIC OF A SHUNT-WOUND DYNAMO WITH HORSE-POWER LINES.

The horse-power curves are interesting in their relations to the characteristic. The ordinate or vertical next to the left-hand axis of ordinates can be used as an ohm line. A straight edge will then give the resistance for each point on the curve. At P it is infinite, because the tangent of an angle of 90° is infinite. The volts at P were obtained on open circuit, which is infinite in resistance.

In the case shown in Fig. 173 the critical current may be called 32 amperes. It is not critical to the same extent as in a

series dynamo. But the long, almost straight descent of the curve toward the origin gives a critical factor. This is external resistance. With insufficient external resistance the electromotive force falls to zero. With infinite resistance it rises to a maximum. At an intermediate resistance, which in this particular case is about one ohm, the power is ready to rise rapidly or fall rapidly for a slight change in resistance. If the outer resistance is increased, the power rises on account of an increase in

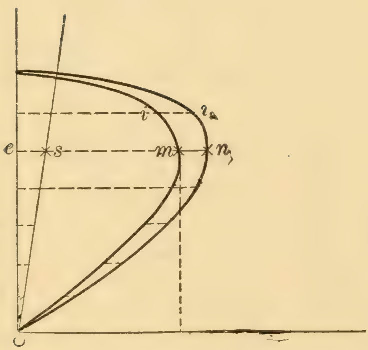


FIG. 174.—OUTER CIRCUIT AND TOTAL CURRENT CHARACTERISTIC IN A SHUNT DYNAMO.

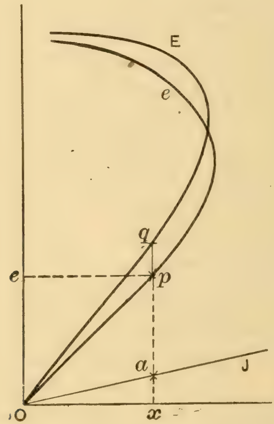


FIG. 175.—TOTAL CHARACTERISTIC OF SHUNT DYNAMO.

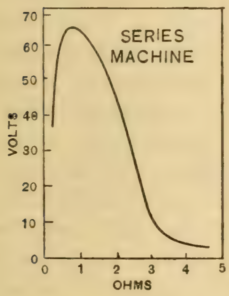
voltage. If the resistance decreases, the power falls by an almost equal decrease of voltage and current.

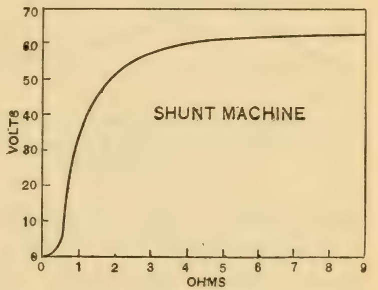
Roughly speaking, the characteristic shows one horse-power with a resistance of 1 ohm and a resistance of 6 ohms. With a resistance of about 1¾ ohms it shows the maximum power, nearly 2 horse-power. These variations in resistance are in the external circuit.

Total Current Characteristic in Shunt Dynamo.—The total current is that which flows through the armature, and which is the sum of currents in the field coil and in the external circuit. The characteristic of the external circuit as just deduced is the

basis. The new one is drawn by adding to the abscissas or to the horizontal lines of the diagram, lengths representing the current which at each given voltage will flow through the field.

In the cut, Fig. 174, the inner of the two curves is the characteristic of the outer circuit. The radius vector is drawn at an angle giving a tangent equal to the armature resistance. A straight line is the characteristic when the resistance is constant. Therefore, the distance *e s* is the amperes of current which would exist in the armature at the voltage corresponding thereto. This and the corresponding lengths are then added each to the corresponding abscissa of the external curve, as at *m n*





FIGS. 176 AND 177.—OHM-VOLT CURVE OF SERIES AND SHUNT DYNAMOS.

and $i\ i_a$ and the new curve is drawn through the points thus determined. The outer curve is the total current characteristic thus constructed.

Total Characteristic of Shunt Dynamo.—So far the curves have been based on potential difference at the terminals. To get the characteristic based on total electromotive force and total current, we start with the curve of total current *e*, Fig. 175. The radius vector J gives the armature characteristic. Take a point *p*, Fig. 175, on the curve of total current. This is on an ordinate denoting *p e* amperes. The voltage of the armature at this current is the length *a x*. This added to *p x*, the voltage at the terminals, gives the electromotive force *q x* at the amperage O *x*. In this way points are found on a curve which give the

relations between the electromotive force and total current, just as described for other cases.

Ohm-Volt Curves.—Curves can be laid out with the resistance of the circuit as one of the elements. In parallel lighting service the resistance of the outer circuit increases as lamps are extinguished, and decreases as they are lighted. The ohm-volt curve is especially adapted for expressing the conditions of such service. Two such curves are shown on a small scale in Figs. 176 and 177, one for a series dynamo, one for a shunt dynamo. For a compound dynamo the corresponding curve is a combination of the two. In Fig. 178 the curves are superimposed. It will be seen that if combined, the result will be a straight voltage line. This is the condition desired for parallel circuit lighting and supply, where the voltage should be constant under all changes of resistance.

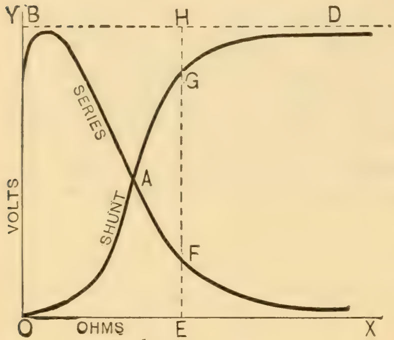


FIG. 178.—COMBINED SERIES AND SHUNT OHM-VOLT CURVES FOR A COMPOUND-WOUND MACHINE.

Thus the sum of E G and E F is equal to H E. This line represents the sum of the voltages of the curves at the resistance denoted by O E. The same summation at other points would give other points representing the sum of the voltages of the two curves at various resistances. The locus of these points, or the place where they would be found, would be a line approximately straight and horizontal; it is the line B D of the cut. The line B D is the combination of the other two curves and indicates their combined action. This action is that of giving identical voltage at varying resistances.

CHAPTER XVI.

THE DIRECT-CURRENT MOTOR.

Direct-Current Electric Motor and Torque.—The direct-current electric motor is a machine driven by the direct current which is generated in any desired way, which current is forced through it by electromotive force. As motors are constructed in modern engineering practice, the driving of the motor causes the armature to rotate. This it does with greater or less force, and the force developed is torque. Torque is a twisting or turning force.

The armature driven around with torque or twisting force is connected to machines, so as to do useful work.

Reversibility of Dynamo and Motor.—It is only a few years ago that the doctrine of the conservation of energy was definitely formulated and accepted as the cornerstone of natural science. In nothing is it better illustrated than in the reversibility of the dynamo and motor. If such a machine is turned by mechanical power, resistance will be encountered if the circuit is closed, and mechanical energy will be absorbed. On the circuit, by the heating of the wire and other means, the presence of electrical energy can be discerned. Energy is conserved. The mechanical energy expended in driving the machine has not disappeared; it has been converted into electrical energy.

In the motor exactly the opposite action takes place. Electrical energy is absorbed by the motor, and mechanical energy is given off by it. It is another example of the conservation of energy. The same machine can act in one or the other *rôle*. In engineering practice an electric machine often automatically changes from motor to dynamo, or the reverse. Sometimes this action is a cause of serious trouble if not detected in time.

Generator and Motor Connected.—If we have two direct-current machines connected by two leads, so as to form a com-

plete circuit, and both are turning, each one in turning will generate electromotive force. Referring now to the cut, Fig. 179, there are shown two such machines connected, and both armatures are supposed to rotate in the direction indicated by the upper arrow. The polarity of the electromotive force due to rotation tends upward from the lower brush to the upper. This tendency is indicated by the arrows on the end of the armature pointing upward.

The condition of things shown in the cut is the operation of a generator and motor on one circuit; both are direct-current and

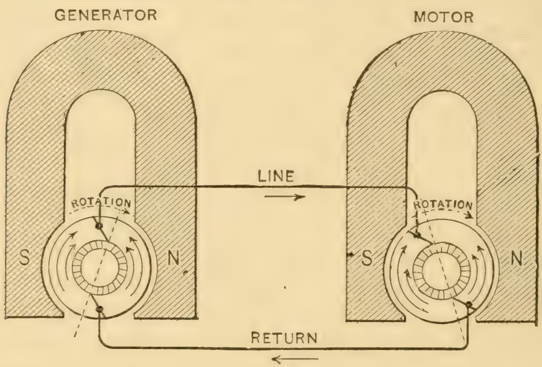


FIG. 179.—CONNECTION OF GENERATOR AND MOTOR.

bipolar. The bipolar type is selected for the sake of simplicity. What is to be noted applies to all direct-current machines.

Counter Electromotive Force.—The left-hand machine is the generator sending current over the line and through the coils of its armature. The latter begins to revolve. As it does so, it generates in accordance with Lenz's law electromotive force, which operates to resist its rotation. This it does by opposing the electromotive force on the line, thereby cutting down the driving current. Such an opposing electromotive force is called counter electromotive force, and is indicated by the arrows on the end of the armature.

This example illustrates a broad principle underlying the operation of direct-current machines primarily. If in a direct-

current machine the electromotive force and current are in harmony with each other, working in the same direction, the machine is a generator. If the current forced through the machine and the electromotive force due to its rotation oppose each other, the machine is a motor.

The above applies to alternating-current synchronous motors operated by single-phase current, as will be seen later.

Action of Counter Electromotive Force.—Counter electromotive force tends to reduce the speed of rotation of direct-current motors. It does this without any direct waste of power. A motor may work with highest efficiency at a certain rate of speed. If the counter electromotive force reduced it below this speed, its efficiency would be reduced, but there would be no direct relation necessarily between the counter electromotive force and the reduction in efficiency. Counter electromotive force is not a hurtful resistance.

Counter electromotive force tends to prevent a direct-current motor from going too fast. The faster its armature rotates, the greater will be the counter electromotive force produced, and the less will be the torque of the machine. The torque will diminish, because the current will diminish as the counter electromotive force increases. As the armature turns against mechanical resistance of various kinds, friction, air resistance, and sometimes a load such as that due to machinery driven by it, the reduction of torque reduces the speed of rotation.

Relation of Speeds of Generator and Motor Connected.—If the two machines are identical, and if the motor turned without any friction or resistance of any kind, the greatest speed the motor could attain would be equal to that of the generator. Identical armatures rotating at identical speed in identical fields of force generate the same electromotive force. In the generator and motor these would be opposed to each other; and when the motor turned at the same speed as the generator, no current would pass. In the condition supposed, the armatures would rotate synchronously, and no mechanical energy would be generated in the generator or expended in the motor. Such synchronism could not possibly exist, as no armature could rotate without experiencing some resistance.

The slower a motor runs, other things being equal, the greater will be the current passing through it, and the greater will be the net electromotive force producing the current. The volt-amperes will be greater therefore as a motor runs more slowly, and slow running is due to increased mechanical resistance. The volt-amperes represent energy absorbed; the mechanical resistance overcome represents energy developed. As is manifestly proper, they increase and diminish together.

Counter Electromotive Force and the Armature.—The armature of a working motor is ordinarily of such low resistance that the current which would pass through it at the potential of the working circuit would heat it so much as to injure it. As the armature rotates it has counter electromotive force impressed upon it, which acts like resistance, and reduces the current passing through it. Counter electromotive force protects the armature from burning out. Reduction of current in the armature reduces torque, so that the turning force of the armature is reduced as its speed of rotation increases. Thus a slowly-turning armature takes more current and exerts higher torque than a rapidly-rotating one. To protect it from burning out a rheostat is generally used to start it, so that it begins rotating with a reduced current, only receiving the full electromotive force of the circuit when it is turning fast enough to protect itself by counter electromotive force.

CHAPTER XVII.

OPEN-COIL AND HOMOPOLAR GENERATORS—SIZE AND OUTPUT OF GENERATORS.

Open-Coil Armature Winding.—The windings of the armature of a direct-current dynamo need not be re-entrant. In the one-coil armature they are disconnected at the ends, as is seen in Figs. 123 and 126, page 220. The old two-pole magnetos and dynamos with single-coil armature of the H type, Fig. 128, page 223, all operated on this principle. The Gramme ring, introducing into the larger field of engineering practice the older Pacinotti principle of closed-coil winding, was hailed as an immense advance. Yet to the present day the open-coil winding is used on some of the most successful dynamos.

The Brush Dynamo uses open-circuit windings. The diagram, Fig. 180, shows the principle of the armature winding. The coils are carried on an iron ring-shaped core, which is a variety of the Gramme-ring core. The coils may be of any even number; for each pair of coils opposite to each other there is what amounts to one two-part commutator.

Returning to the diagram, Fig. 180, the outer end of each armature coil is connected to a commutator bar or segment, as indicated in plane development. The inner ends of each pair of opposite coils are connected across the armature to each other.

When a pair of coils are in the neighborhood of the vertical line, or in the position of coils C_1 C_2, the maximum number of lines of force are passing through them. For the instant the path of these lines of force coincides with the path followed by the coil, so that there is no change in the number passing through the coil for that instant. Hence the coil is inactive and is out of circuit, no brush contacts being made with its commutator segments.

From the coils A_1 A_2, which on account of armature reaction

are in the position of best action, current is taken by the brushes P Q. The arrows give the direction of the current. From brush Q the current goes to brush R. The coils B_1 B_2 have left the position of best action, and hence have less electromotive force impressed upon them than have the coils A_1 A_2. The same applies to the coils D_1 D_2 as regards electromotive force, for converse reason, that these coils D_1 D_2 are approaching but have not reached the position of best action. The brush Q, taking the

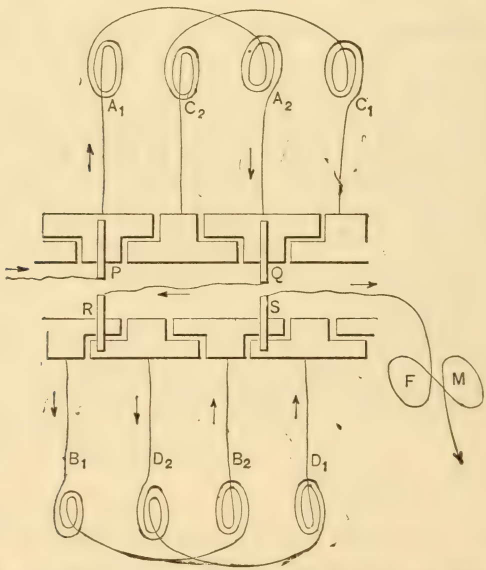


FIG. 180.—DEVELOPMENT OF THE BRUSH DYNAMO WINDING.

current from A_2, delivers it to the B and D coils, four in number, in parallel of two, by the brush R. It divides between them, reunites at brush S, goes through the field F M, and outer circuit back to P.

The object of dividing the current between coils B_1 B_2 and D_1 D_2 in parallel is in a sort of accordance with Ohm's law. The electromotive force in these coils being below the maximum, the resistance is also reduced by connecting them in parallel.

Each pair of coils in a Brush machine can be pictured as representing an open-coil independent armature of two coils. Thus an eight-coil machine is in a sense equivalent to four independent machines, caused to co-operate in producing a pulsating direct current.

Brush Dynamo Construction.—In Fig. 180*a* is shown a Brush dynamo with its upper field section removed and its armature hoisted up out of its bearings. It shows the ring armature with grouped windings. On the shaft are rings of larger diameter

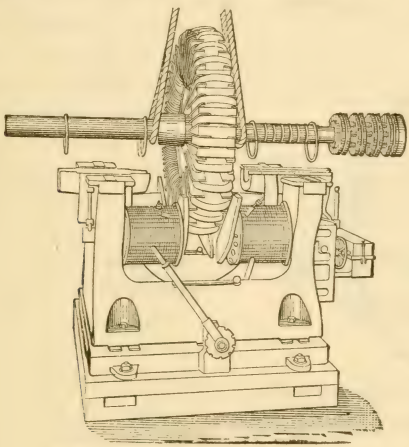


FIG. 180*a*.—BRUSH DYNAMO.

than that of the shaft which carries them. These are oiling rings. When the armature is in place, these hang with their lower section immersed in oil. As the shaft rotates they turn also, traveling around it and carrying up oil to it so as to continuously feed the bearings with oil. This is termed ring oiling.

The Thomson-Houston Armature is wound on the open-circuit principle. The armature contains a group of three coils, or three sets of coils and a three-part commutator. The coils are wound on a hollow spheroidal frame, and the resulting armature is nearly spherical in shape. The coils are all wound in the same sense, right or left-handed. Three ends of the coil windings are connected together; the other three ends go to three commu-

tator divisions. In the newer machines a ring armature has been used.

The diagram, Fig. 181, shows the connections. Three ends of the coils are connected together at D, as shown; three go to the commutator segments, A, B, and C. The small arrows show the direction of the current.

The coils consist of numerous turns of wire; the diagram shows each as a single turn for the sake of simplicity.

The next diagram, Fig. 182, shows the coils as three radii, A, B, and C, connecting three commutator segments. Each radius represents a great number of turns of conductor on the core. F P are four brushes; L L indicate lamps on the outer circuit. Arrows show the direction of the current, and a curved arrow shows the direction of rotation of the armature. The dotted lines *m n* show the position of the neutral line of the field.

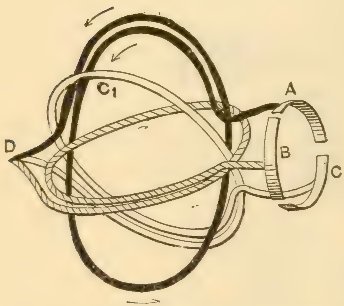


FIG. 181.—THOMSON-HOUSTON ARMATURE WINDING.

Coil B in the diagram is in the neutral position, and is cut out. The positions of coils A, B, and C may be referred to the figures on a clock face. B is at 10 o'clock, A is at 2 o'clock, and C is at 6 o'clock. In this position current goes from C to A. When the armature turns so as to bring B a little further on, it connects with the brush F′, and this coil B through the brush F′ and the coil C through the brush P′ work in parallel with each other and in series with A. Next C moves on toward 4 o'clock, and is cut out, leaving A and B working in series with each other. As A passes on toward 10 o'clock, just before it parts company with the brush P, the brush F comes in contact with C, and A and C are in parallel with each other and in series with B.

In practice the angular distance between the brush ends P′ and F′ and the brush ends P and F is about 60° respectively, and this keeps the parallel pair of coils in parallel with each other for some considerable part of the rotation.

The dynamo is automatically regulated by moving the brushes F F′ backward or away from P P′, and shifting P P′ forward when more current is needed and *vice versa.* If the angular distance between the brush ends P and F and the brush ends P′ and F′ is 60°, there will be no period when all the section coils are not doing something, two being always in parallel with each other. By bringing the brushes closer together the current is diminished by increasing the period of time during which one of the coils is cut out and inactive.

Homopolar, Acyclic or Unipolar Dynamo.—We have seen that a closed ring swept through a uniform field of force has no current induced in it, although electromotive force is impressed on it. Electromotive force is impressed upon its two halves of

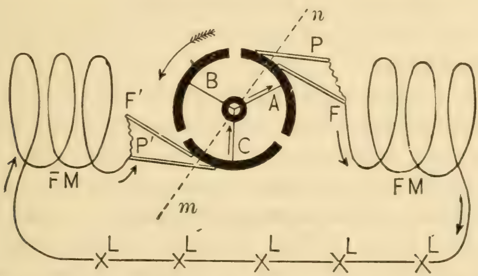


FIG. 182.—DIAGRAM OF CIRCUITS OF THOMSON-HOUSTON DYNAMO.

the same polarity in each, so that they counteract each other. If to opposite ends of the horizontal diameter of the ring, as shown in the drawing, Fig. 115, the ends of a conductor were connected, current would go through it. A simple conductor representing the vertical diameter of the circle could take its place, and naturally would. A current is thus produced by sweeping a conductor through a uniform field of force, and without varying the number of lines of force which are interlinked with the circuit. A generator constructed on this basis is named as above.

Up to the present time, comparatively few have been made.

Various ways of producing the field can be used. Let cylindrical north and south poles of a dynamo face each other. The axis of the armature corresponding with the center of the cylin-

drical field, radial conductors swept through it will have electromotive force impressed upon them, and if one brush connects with the inner and one with the outer end of a radial conductor, current can be taken from the brushes. The conductors cannot be connected as in ordinary dynamos, but the brushes must take current from opposite ends of the conductor. Any number can be put in the armature, and are connected to collecting rings, so as to carry out the principle described.

Two north poles may be placed within two south poles, thus making an annular or ring-shaped field. A conductor swept through this field, and lying parallel with the axis of the field, will have electromotive force impressed upon it, and a current can be taken from brushes connecting with its ends. Any number of conductors can be placed in the field, so as to form a hollow cylinder. They cannot be connected, as in a drum armature, or one will counteract the other. The current has to be taken from their ends.

Owing to the absence of a commutator, this type of machine presents great advantages as a generator of direct current. Its names are derived from the feature that the active conductors move through a field of uniform or unvarying density.

Relation of Size and Output of Dynamos.—Considerable discussion has been given to the question of the relation of the sizes of identically-shaped electric current generators to their respective outputs. If a dynamo is reproduced in all its relative proportions, but of double the linear dimensions, what will be the relative power output of the two?

Manufacturer's and Thompson's Rules.—One rough rule is to treat the output as varying with the weight. This is a manufacturer's rule, a mere approximation to accuracy. It is expressed in mathematical terms by saying that the capacities of identically proportioned dynamos vary with the cube of the linear dimensions. Prof. Silvanus P. Thompson has given the fifth power of the linear dimensions as the correct figure.

If one dynamo was twice as large in linear dimensions as another, it would, according to the "manufacturer's rule," have eight times the capacity of the smaller one; according to Prof. Thompson's rule, it would have thirty-two times the capacity.

This is a considerable discrepancy. Yet if we investigate it on a purely proportional basis, the discrepancy may be still greater.

Deduction of Thompson's Factor.—Assume a dynamo of double the linear dimensions. The length of the magnetic circuit will be doubled. For identical value of magnetization or $\mathfrak{B}$ twice the ampere turns will be needed. The wire on the field will have twice the diameter on the large dynamo of that of the wire on the small one. This will give it the same number of turns, but four times the capacity for current. Therefore the intensity of field or $\mathfrak{B}$ will be multiplied by four on account of the increased current, and divided by two on account of the greater length of magnetic circuit, giving half the permeance per unit of cross section. This is a net increase of field intensity to twice that existing in the smaller dynamo.

The field will have four times the cross-sectional area. Therefore being of twice the intensity, the lines of force in it will be $4 \times 2 = 8$, or eight times as many as in the smaller dynamo.

The armature will have twice the linear dimensions of the smaller one, and therefore can carry twice the turns of wire per layer and twice as many layers as the smaller one carried. This gives four times as many convolutions. If it rotates at the same number of revolutions per minute as does the smaller armature, it will cut $8 \times 4 = 32$, or thirty-two times as many lines of force as did the armature one-half its size in linear dimensions. This gives thirty-two times the voltage. This coefficient 32 is the fifth power of 2, or $2^5 = 32$. If we stopped here, we should have Prof. S. P. Thompson's figure. The output of a dynamo is governed by the voltage it can produce, and by the amperage it can carry. The size of the armature wire controls the amperage. It must not be subjected to so heavy a current as to get overheated. If it is assumed to be of the same size in the larger as in the smaller dynamo, the larger one will give the same current at thirty-two times the voltage, which gives thirty-two times the capacity in watts.

The rule of the fifth power thus deduced is not rigorously accurate, because sources of loss vary with the sizes of dynamos, and tend to favor the output of the larger sizes.

In the above calculation a doubling of intensity of field mag-

netization is assumed. This is not to be looked for in practice. With equal excitation, the output would be reduced to 16, or 2^4 times that of the smaller.

The Sixth-Power Rule.—If we assume the air gap to be increased in depth or thickness, and the same field intensity to be maintained, we can get a still higher result.

Assume the field of equal intensity to be of four times the area. Assume that the same voltage is to be impressed on the circuit. Then one-fourth the windings are required on the armature, as there are four times as many lines of force in the field. To put one-fourth the windings on an armature of twice the circumference, the wire should have eight times the diameter of the wire on the smaller armature. But a wire of eight times the diameter of another one can carry $8^2 = 64$, or sixty-four times the current, giving an output sixty-four times as great as that of the generator which is half its size in linear dimensions.

Both of these deductions are on the basis of an equal number of revolutions of the armature per minute. It would be nearer truth to take an identical peripheral velocity.

This would reduce 2^5 or 32 to 2^4 or 16, and 2^6 or 64 to 2^5 or 32. The latter figure allows for an increase of the thickness of the air and copper gap in the larger machine to eight times what it was in the smaller one. This is certainly excessive.

Calling n the relative linear size of the larger dynamo, the authorities give the student his choice of the following powers of n to express the increased output of the n times larger dynamo:

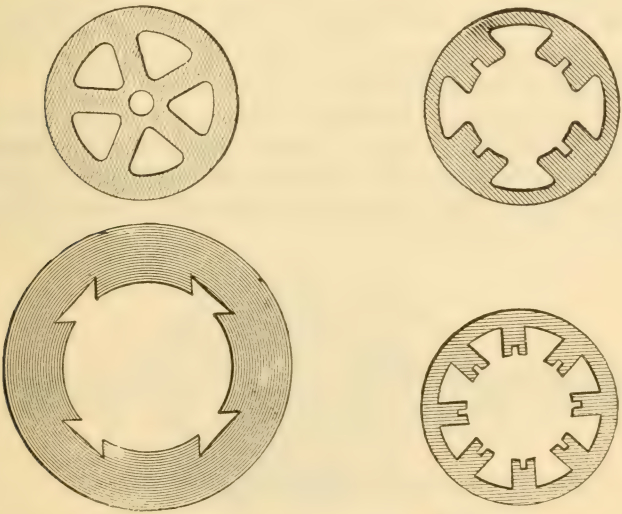
Prescott	n^2
Mascart and Joubert..........................	n^2
Hopkinson	n^3
Rechniewski	n^3
Manufacturer's Rule, a little over...........	n^3
Ayrton	$n^{3.7}$
Frolich	n^4
Deprez	n^5
Thompson, S. P...............................	n^5

All things considered, the fourth power or n^4 is a safe figure to take.

CHAPTER XVIII.

GENERATOR AND MOTOR CONSTRUCTION.

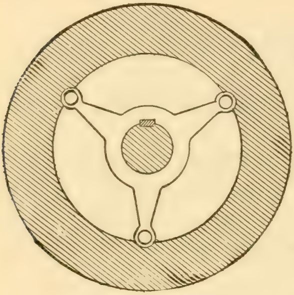
Disks for Smooth-Surface Armature Cores.—To prevent the production of eddy currents of serious intensity, armature cores are built up of thin sheets or disks of iron. Disks are cut to give the cross section of the drum, and are laid up with sheets

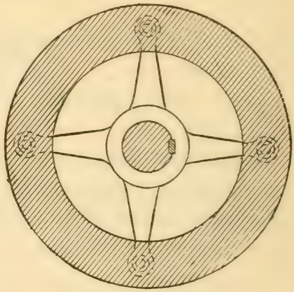


FIGS. 183 TO 186.—SMOOTH-CONTOUR CORE DISKS.

of paper intervening to form a cylindrical pile. The disks are often cut with a large hole in the center. They are often fastened together with bolts, which run through the pile of iron and paper from end to end. The bolts are insulated by tubes of insulating material. The cylindrical core thus produced may be

keyed directly to the main shaft, or is carried by spiders. The cuts, Figs. 183 to 188, show various examples of core disks with





FIGS. 187 AND 188.—SMOOTH-CONTOUR CORE DISKS WITH SPIDERS.

smooth contour. Sometimes the core is built up of segments of disks, as shown in Fig. 189.

Disks for Grooved Armature Cores.—A general practice in drum armatures is to have a series of longitudinal grooves in the cylindrical core surface to receive the conductors. Disks for these are cut out with peripheral notches, as shown in Figs. 190 to 192.

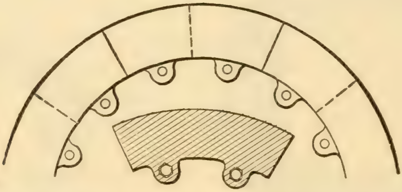
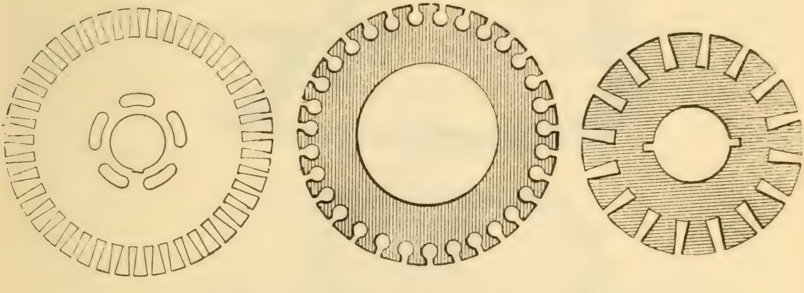


FIG. 189.—SEGMENTAL CORE DISK CONSTRUCTION.

However carefully the piling up of such disks is done, the notches or grooves are not to be relied on as being perfectly true and smooth. Smoothness is essential to avoid cutting the insulation. Accordingly, each core thus built up is often placed in a filing machine, where the long grooves are filed out one by one until they are of exact size and smooth. This constitutes the armature core, which is keyed to the armature shaft of the machine. In Fig. 193 is shown such a core.

Formed Coils.—The material of the winding differs for different machines. It may be composed of round wire, of square wire, or of flat bars. In some works each coil is shaped on a form to



FIGS. 190 TO 192.—DISKS FOR GROOVED ARMATURE CORES.

the exact contour of the place where it is to lie on the armature. In the case of a heavy bar of copper, this exacts some rather elaborate bending. Sometimes an iron jig is used for this purpose, sometimes it is done largely by hand process. In any case, each

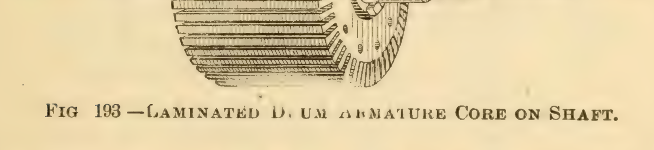
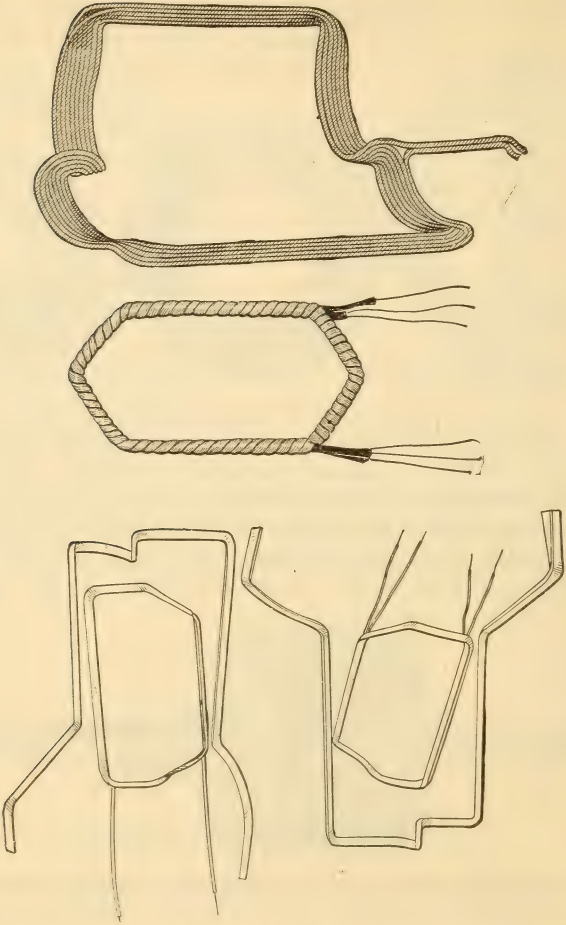


FIG 193.—LAMINATED D. UM ARMATURE CORE ON SHAFT.

coil or element appears as an irregular rectangle. Such coils are termed formed coils. American practice favors the use of formed coils, whenever it is possible to employ them. They are shown in Figs. 194 to 196.

Wire Winding.—The older way of winding armatures was the simple process of hand-winding with insulated wire. This is



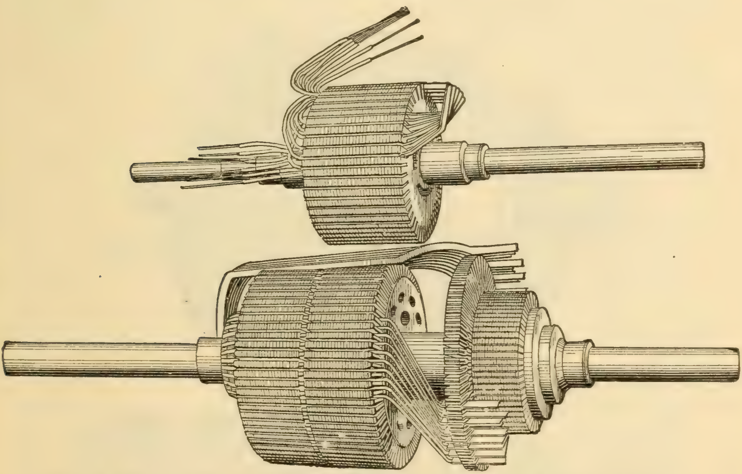
FIGS. 194 TO 196.—FORMED COILS FOR ARMATURES.

still used to a considerable extent, but formed coils for dynamos and other electric apparatus are typical of modern methods.

Insulation of Conductors.—Alcoholic solution of shellac is much employed in insulating armature conductors. Formed

conductors are taped, shellacked, and baked before being set into the grooves on the armature core.

Core Grooves and Wooden Wedges.—Little notches are sometimes formed in the notches in the core disks. When the core is built up, these give a dovetailed groove next to the periphery or surface of the core. Long slips of wood are driven into these grooves and above the windings, holding the latter firmly in

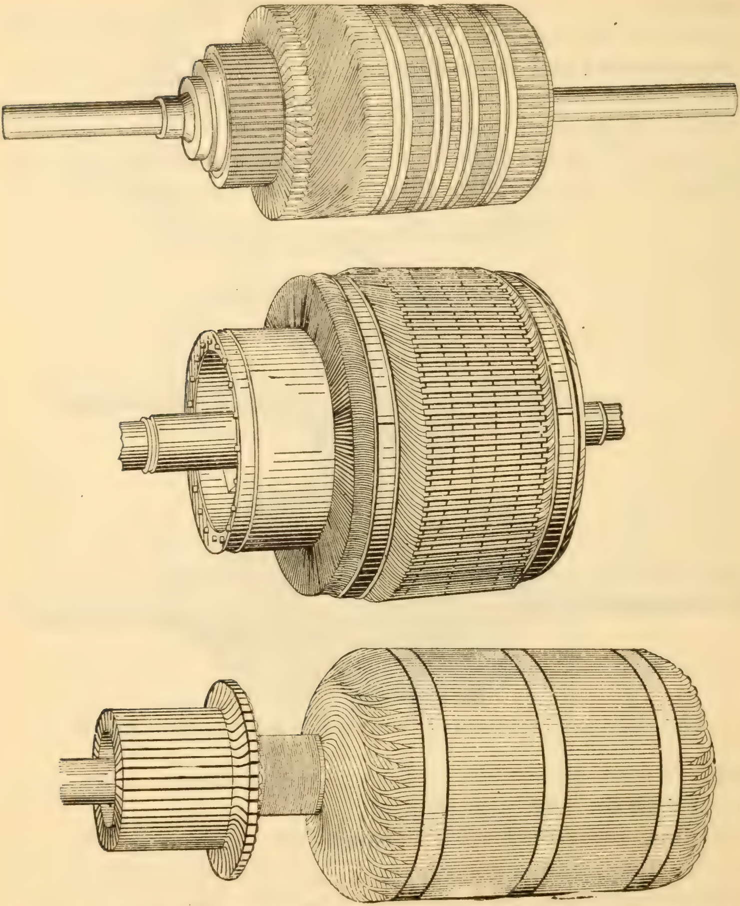


FIGS. 197 AND 198.—WINDING ARMATURES WITH FORMED COILS.

place. Wire bindings are wound around the whole in three or more places for additional security.

Winding Armatures with Formed Coils.—The cuts, Figs. 197 and 198, illustrate the insertion of formed coils in the grooves in armature cores, and the next cuts, Figs. 199, 200, and 201, show armatures completely wound.

Pole Armatures.—This type of construction is not very much used, except for alternating currents. The cut, Fig. 202, shows a sectional view of a multipolar pole armature in a multipolar field. As the armature rotates, its windings are carried through high intensities of field, when pole faces pole as in the cut. In the position when armature poles would face the space be-



FIGS. 199, 200 AND 201.—ARMATURES COMPLETELY WOUND.

tween field poles, the field would be weak. Thus, in rotating the armature coils would be interlinked with constantly-varying numbers of lines of force, so that currents would be induced in them. The construction shown is that used for the Ganz-Zipernowski alternator, but will serve to show the principle of the polar

type of armature. Fig. 202*a* shows a multipolar structure which may be an armature or a revolving field.

Disk Armature.—This is also a type of armature which is but little used. Fig. 203 shows a field magnet producing a field of force of straight lines. The spaces on one or the other side of the poles have an exceedingly weak field. To show the action of the poles, a wire conductor is shown, which moved in the direction of the large arrows would have electromotive force impressed upon it of the polarity indicated by the small

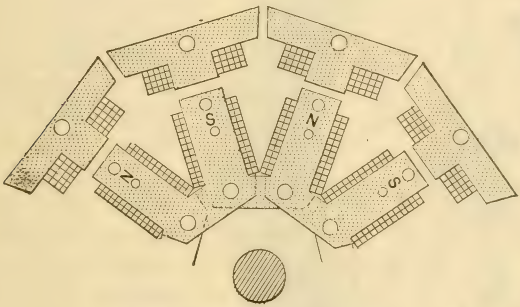


FIG. 202.—POLE ARMATURE.

arrows in Figs. 203 and 203*a*. The last-named cut shows the complete set of coils of the armature, part only of which is shown in Fig. 203.

The next cut, Fig. 204, shows the section of the active field of a disk dynamo, through which such coils as those shown in diagram in Fig. 205 are swept.

Commutator Construction.—The commutator is built up of a number of bars of nearly rectangular section. They are made of hard-drawn copper. They are put together like the staves of a barrel, the periphery being made up of their edges, not of their flat sides. It is as if the staves of a barrel were but an inch in width and several inches deep or thick. The commutator bars have placed between them strips of insulating material, made partly or entirely of mica.

Mica is an excellent insulator; it is mechanically strong, can be bent to a considerable extent, and is absolutely non-combustible and unaffected by any heat it can ever be subjected to on a dynamo or in electrical machinery. No substitute for it has ever been found. It is made up into various preparations, resembling cardboard, and these are put upon the market by various manufacturers.

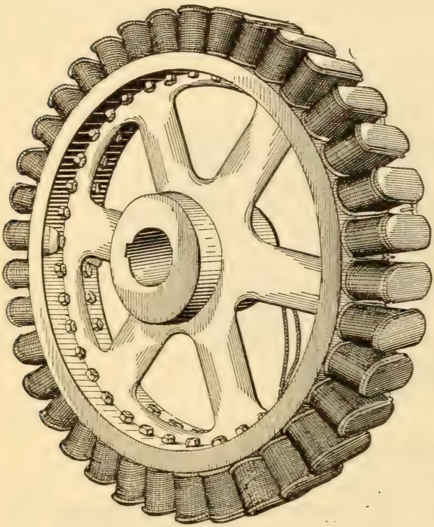


FIG. 202*a*.—MULTIPOLAR ARMATURE OR REVOLVING FIELD.

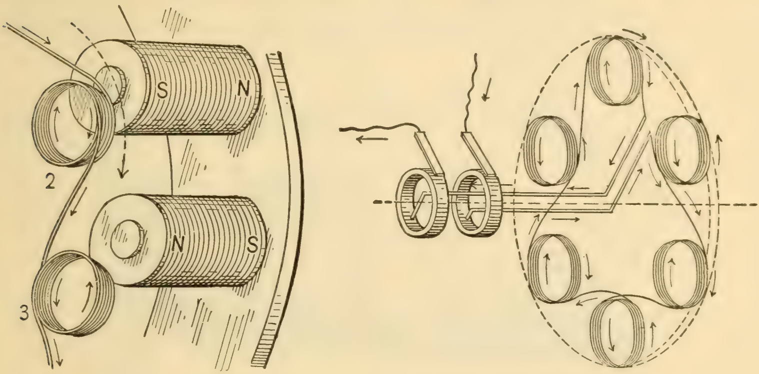
A hollow cylinder with thick walls is built up of the copper bars and insulating strips, and the pieces have to be firmly secured without any electrical contact between them. They must be rigidly held in position, because the commutator has to be turned up between centers, and any motion of the bars would be fatal to securing a cylindrical surface. The surface has to be cylindrical, or the brushes will jump and chatter. A high bar or one out of position will interfere with the action of the machine. The bars must be secure from displacement.

The cuts, Figs. 206 to 209, show various constructions of commutator. The heavy dark lines indicate insulation. The views are given in section, and are self-explanatory.

The function of the commutator is usually to transfer the rubbing contact from outside periphery to a drum of relatively small diameter. In some machines the commutator is of almost the full diameter of the armature. In any case it provides a smooth cylindrical surface for the brushes to rest upon. In the drum and ring armatures the brushes could take the current from

the conductors on the periphery of the drum or ring as the case may be, were it not for mechanical considerations.

Position of Commutators.—The commutator is keyed on the



FIGS. 203 AND 203*a*.—DISK ARMATURE INDUCTION.

armature shaft. It must be accurately in center with it, and its surface must conform to the requirements stated. The end disks or spiders which hold it to the shaft are seen in the cuts, and the insulation between them and the commutator bars is

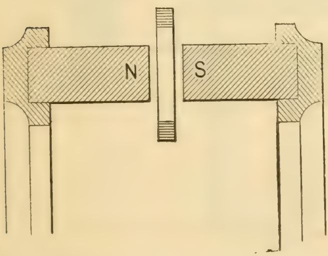


FIG. 204.—SECTION OF FIELD AND ARMATURE OF DISK DYNAMO.

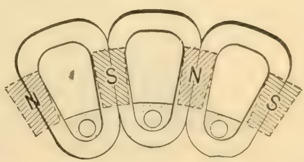


FIG. 205.—ARMATURE COILS OF DISK DYNAMO.

shown in the cuts. In Figs. 199, 200, and 201, page 302, are shown different arrangements of commutators and armature.

Brushes and Brush Holders.—The name brush is applied

to the conductor, generally very unlike a brush, which bears against a moving surface, also a conductor, so as to make an electric contact. The moving part may be a simple insulated ring upon a rotating shaft, it may even be a shaft, or is a commutator with conducting segments insulated from the shaft and from each other.

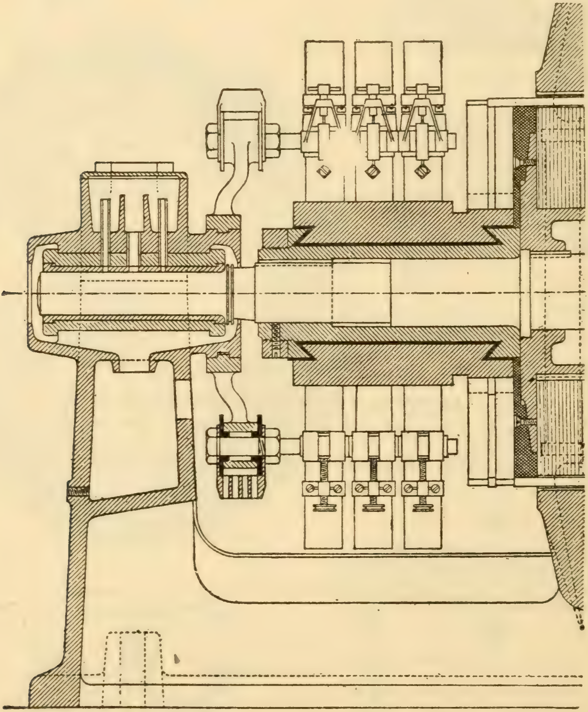


FIG. 2'6 —SECTION OF COMMUTATOR AND BRUSH MOUNTING.

In direct-current dynamos such as are being now described, the brushes bear against the cylindrical surface of the commutator.

Tangential Brushes.—The first brushes were springs of metal placed tangentially, and pressing against the ring or commutator. These were succeeded by compound brushes made of a number of pieces of copper secured one on top of the other and

beveled and trimmed accurately square at the end, so as to line with the commutator divisions. Wire gauze is a constituent of some brushes, and carbon bearing directly or radially on the

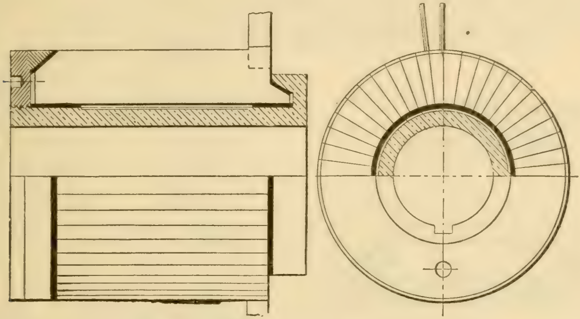


FIG. 207.—COMMUTATOR CONSTRUCTION.

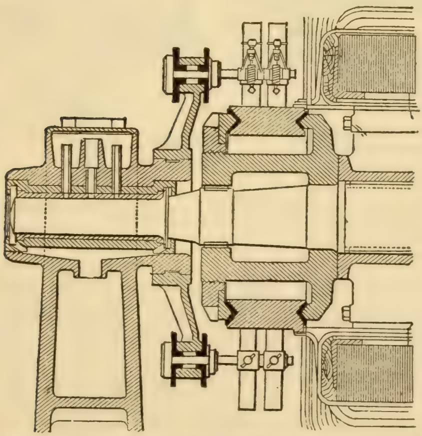


FIG. 208.—SECTION OF COMMUTATOR AND BRUSH MOUNTING.

surface of the commutator is now the generally accepted type of brush. It presents advantages not possessed by other brushes.

Trimming Metal Brushes.—Metal brushes must fit the commutator circle with their hollow beveled ends, and must be

trimmed perfectly square. Gauges are provided for the purpose. A sharp cold chisel may be used, or a shears may suffice. A little touching up with a file may be needed. If a file is used, no filings must be left on the metal, as they might stick between the commutator segments and short-circuit the bars.

Radial Brushes. — The construction of a radial carbon brush and brush holder is shown in the cut, Fig. 210. A block of carbon is held in a socket. The block must move freely in the socket

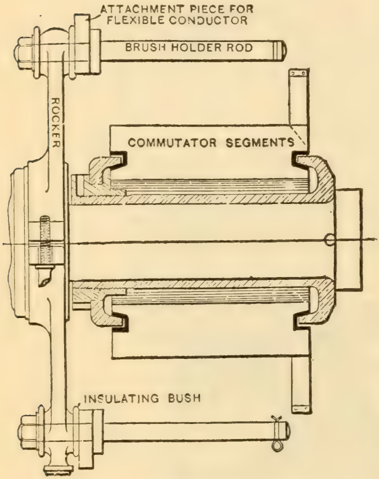


FIG. 209.—SECTION OF COMMUTATOR AND BRUSH MOUNTING.

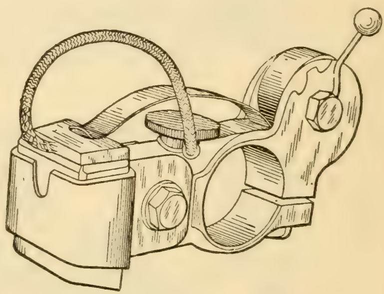


FIG. 210.—RADIAL BRUSH AND HOLDER.

and must be free from side shake. It is pushed downward by a flat spring, and rests upon the commutator surface. The lower surface of the carbon is shaped to fit the commutator. The spring is so long that its pressure is sensibly even for different lengths of carbon blocks. The carbon blocks constantly wear, so this feature of even pressure, whether they are long or short, which is equivalent to old or new, is a valuable one.

Another brush mounting is shown in Fig. 211. Here the brush is fastened in a socket by a clamping screw, and a spiral pressure spring forces the brush against the commutator. The block is held by strips of hard copper, which act like springs and conduct the current.

An important advantage in radial brushes is that if an armature accidentally in starting or stopping, or while out of action, should be turned backward, radial brushes will be uninjured, while tangential or inclined ones will probably get caught in the commutator and be bent back and injured, so that they will require straightening and trimming before the dynamo can be started again.

Position of Opposite Brushes.—Brushes on opposite sides should not be set so as to bear upon exactly the same zone of

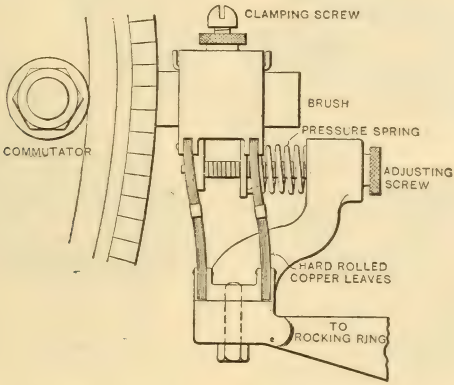


FIG. 211.—RADIAL BRUSH AND HOLDER.

the commutator. They should be staggered a little, so as to bear upon the whole surface of the commutator as near as may be.

Brush Rigging.—In multipolar machines, the brushes are sometimes carried in sets on two insulated rings, which are carried on a metallic ring. For the latter a seat is turned in the frame of the machine. In Fig. 212 is illustrated the "brush rigging" as it is called of an eight-pole machine, and the next cut shows a set of the brushes. The mounting of a brush of one of these sets is shown in Fig. 211. The two rings are called the positive and negative bus rings.

A commutator is always apt to wear a little uneven. The brush holders are made as light as possible, so as to follow any irregu-

larities of shape of the commutator. A properly-treated commutator with brushes of good quality will wear very evenly.

Relation of Depth of Air Gap to Sparking.—To avoid sparking, equal induction should be exerted by each pole. This is insured by equal permeance of the magnetic circuit. An unequal depth of air gap is the most potent disturbing cause. Some irregularity often results from wearing of the bearings, which throws the armature out of

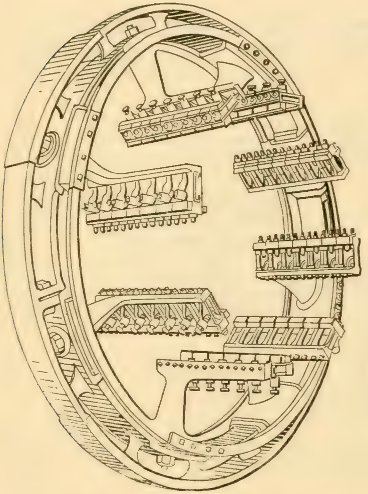


FIG. 212.—BRUSH RIGGING FOR A MULTIPOLAR DYNAMO.

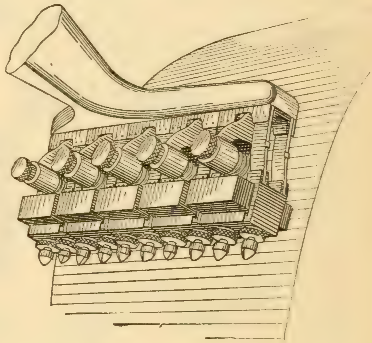


FIG. 213.—BRUSHES OF SAME BRUSH RIGGING.

center, and diminishes the air gaps on one side and increases them on the other. To minimize the trouble resulting from this displacement, it is a standard practice to make the air gap rather deep. A small displacement of the armature shaft under these circumstances has less disturbing effect than it would with very small air gaps. A reduction of a thirty-second of an inch would not be of much effect in a half-inch air gap, while the same reduction would reduce a one-sixteenth-inch air gap fifty per cent, and bring about very irregular or one-sided induction.

Field Magnet for Multipolar Dynamos.—Almost all large dynamos are now made of the multipolar type. The poles are often short cylinders carried on the inner surface of a heavy polygonal

or circular iron frame as shown in Figs. 214, 215, and 216. The poles project radially toward the center. The frame constitutes the field yoke. It is often made in two parts joined on the horizontal diameter, and the poles lie on the diagonals of the circle as shown. The effect of this is that the upper half of the field can

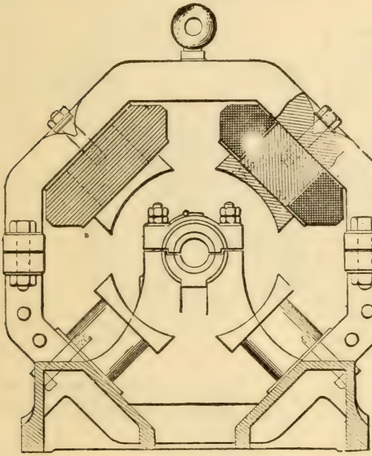


FIG. 214.—FOUR-POLE DYNAMO FRAME WITH SECTION OF WINDING ON ONE POLE.

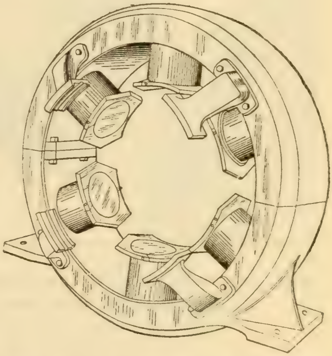


FIG. 215.—MULTIPOLAR DYNAMO FRAME SHOWING BRACKETS FOR CARRYING BRUSH RIGGING.

be lifted off without touching the armature surface, a very essential requirement, as any rubbing of pole face against the surface of the windings might injure the insulation.

In some machines the pole pieces are made of steel and cast-welded into the frame. This process is executed by imbedding the pole pieces in the mold, letting their ends project into the space where the metal for the semi-circles of the field frame is to run. The melted cast iron makes a perfect joint with the steel.

Cast-iron pole pieces are used upon some of the machines.

Formed coils are often used on poles as shown in Fig. 217. Sometimes they are wound with flat conductors bent edgewise as shown in Fig. 217*a*.

To illustrate what has preceded, the cut, Fig. 218, may be re-

ferred to. It shows the principal parts of a four-pole dynamo, the rear post, which carries the armature bearing, being omitted to avoid confusion. The ring system of oil feeding is used, and

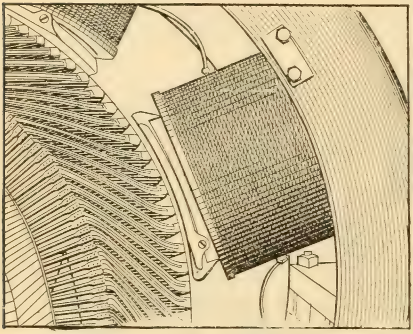


FIG. 216.—POLE AND POLE WINDING OF MULTIPOLAR DYNAMO.

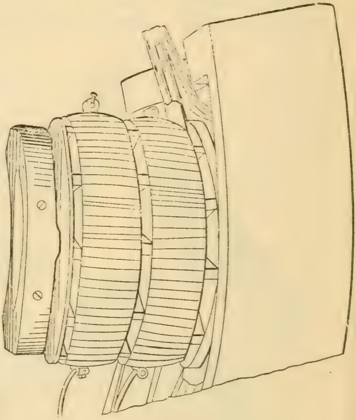


FIG. 217.—POLE WINDING WITH FORMED COILS.

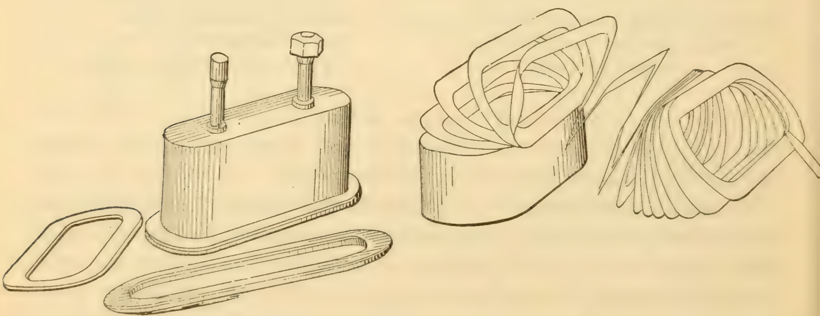


FIG. 217*a*.—EDGEWISE BENT FIELD WINDING AND POLE

ring oilers are shown under the left end of the edgewise armature shaft. The loose rings when in place rest upon the revolving shaft bearing and turn with it, picking up oil and feeding it to the shaft.

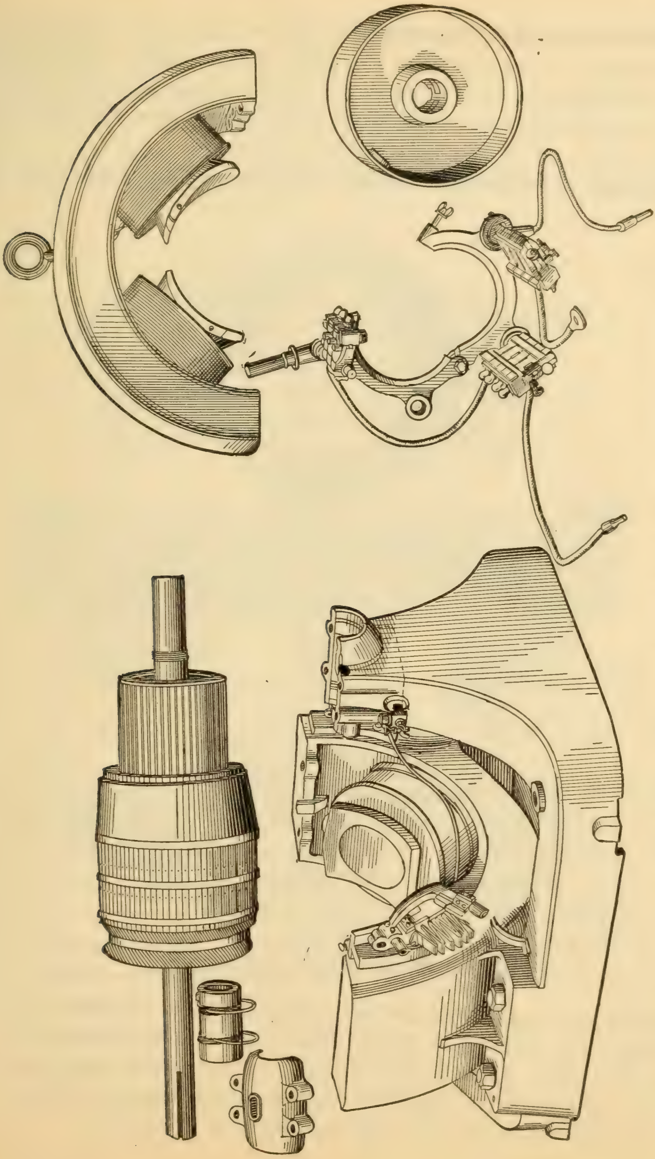
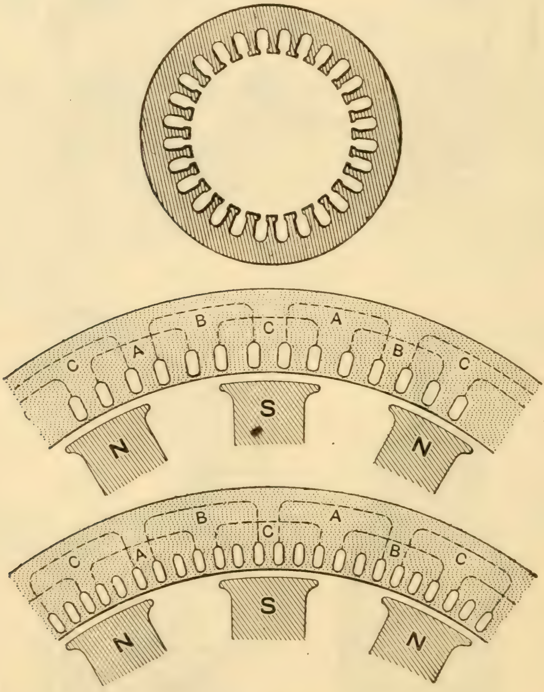


FIG. 218.—PRINCIPAL PARTS OF A FOUR-POLE DYNAMO.

Laminated Field Magnets.—Sometimes the field is made up of laminations cut as shown in Figs. 219, 220, and 221. The windings lie in the inner notches, and are so placed as to establish alternate poles all around the circle. The plates are insulated with paper.

Sectional Laminated Field Magnets.—The laminated field

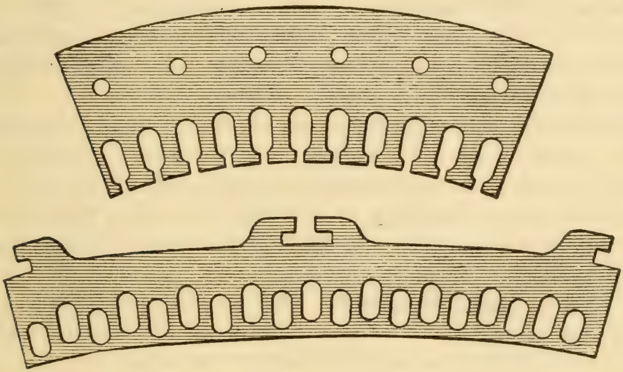


FIGS. 219, 220 AND 221.—LAMINATED FIELDS.

magnets on large dynamos are often made in sections, as shown in Figs. 222 and 223. These pieces are bolted together so as to form a circle. It will be noticed that the lower one has perforations, and not notches. The windings are passed through these holes, and a very solid construction is the result.

Such fields as those shown in Figs. 219 to 223 are most used in alternating-current generators.

Details of Multipolar Field Windings.—The windings of the field poles are often made on tin spools with deep flanges, the surface being most thoroughly insulated by mica, paper, and cloth. One by one these are wound full of wire, which is shel-



FIGS. 222 AND 223.—SECTIONAL LAMINATIONS FOR FIELD MAGNETS.

lacked and baked, so as to produce a solid mass, ready to be slipped upon the pole.

A laminated pole piece placed over the end of each cylindrical pole holds the winding in place. It projects on both sides of it, and is hollowed out accurately to the circle of the armature. The space between it and the armature constitutes the air gap.

The field castings have to be carefully machined before being set up. The bases and joint faces are planed off, the sections are bolted together, and the inner faces of the poles are then turned off.

CHAPTER XIX.

THE ALTERNATING CURRENT.

Alternating Electromotive Force.—Although the term alternating current is universally used, alternating electromotive force is its producer, and precedes it often. The true original is generally alternating electromotive force.

An alternating electromotive force is one which alternates in polarity, regularly or in obedience to some law. It starts at a value of zero, rises to a maximum of one polarity, descends to a value of zero again, changing in direction reaches a maximum of opposite polarity, whence it returns to zero again. These alternations are repeated over and over again.

Cycle, Wave, and Frequency.—The changes described in the last sentence constitute a cycle or wave of alternating electromotive force. If for the word "polarity" we substitute the word "direction," the sentence will describe a cycle or wave of alternating current. When a wave of alternating current or of alternating electromotive force reaches its point of greatest value, the whole circuit is affected; when it reaches zero value, the whole circuit is at zero. The expression wave must be clearly understood. It does not mean that waves run over the circuit, but it does mean that the whole circuit passes simultaneously through the values of the cycle, ranging from zero to a maximum in one direction, back through zero to a maximum in the other direction, and then back to zero, completing a wave. The number of waves per second is called the frequency of the alternating electromotive force or current.

Electromotive Force and Current Curve.—We often gain in our conceptions of things by analogies. It is evident that the action of such electromotive force is analogous to that of a wave. A line representing the cross section of a wave would be a con-

venient way of picturing to the mind the action of alternating electromotive force. It is so good a representation that it is universally used.

Such a line is shown in the cut, Fig. 224.

The horizontal line is what the geometrician would call the locus (place) of zero values. The vertical lines are drawn of length corresponding to the distance of points of the curve from the horizontal or base line. They are called ordinates of the curve. The curve comprises one full wave or cycle.

The portions of the curve below the horizontal line represent the electromotive force of one polarity; the portions above the line that of the other polarity. The lengths of the ordinates represent the strengths of the electromotive force. The shape of

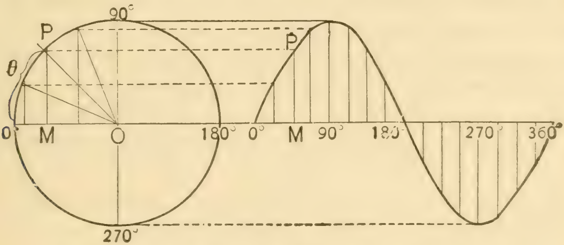


FIG. 224.—SINE CURVE OF GENERATING CIRCLE.

the curve represents the way the electromotive force increases and diminishes.

If the proper conditions prevailed, an alternating current of exactly identical form would be produced by the alternating electromotive force. A similar curve would represent the current, its ordinates would indicate by their length the intensities of the current. Their position above or below the zero line would indicate the direction of the current constantly changing; for part of the cycle in one direction and for part of the cycle in the reverse direction.

The current is the factor generally referred to in practice; alternating electromotive force is its invariable cause and concomitant. An alternating-current generator is also an alternating electromotive force generator, and an alternating-current sys-

tem is an alternating electromotive force system. It is thus through all the branches of alternating-current work. But the expression "alternating current" is always used, except where there is special reason for using the other expression, "alternating electromotive force."

Production of Alternating Electromotive Force and Current.—Alternating electromotive force is impressed upon a circuit by means of a special type of electric machine called an alternating current dynamo, alternating current generator, or alternator. In practice the armature contains one, two, or three separate windings. The terminals of the windings are connected to various numbers of leads constituting the outer circuit. The armature is so wound that its entire winding is simultaneously impressed with the same electromotive force at the same instant, but this electromotive force varies though the values of the wave or cycle just described. In turning through the arc represented by the quotient of 360° divided by half the number of poles in the field of the alternator, one cycle or wave of alternating electromotive force is impressed upon each of the armature windings and circuit.

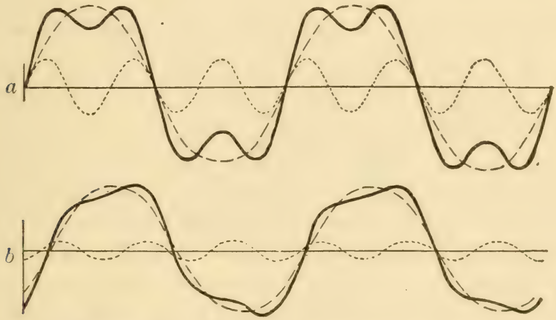
The above is strictly true for typical alternators, but is subject to modification for some constructions.

Length of a Wave.—A wave curve is divided into or measured by 360 parts. This refers its length directly to degree measurement, as there are 360 degrees in a circle. Such system harmonizes with the fact that alternating electromotive force is always generated by the circular motion of an armature or field, and that a single wave is produced by a complete rotation of the armature or field through 360 degrees, or by a rotation through an integral portion of 360 degrees.

Form of Alternating E. M. F. and Current.—The form of the curve represents the nature of the variations of the electromotive force or current, as the case may be. The form of a current is the nature of its variations, and is graphically represented by its curve. The same applies to electromotive force. An alternating current may increase slowly or suddenly, by an even curve or a series of jumps, and may return to zero value in various ways also. If it is to be represented by a curve, the irregu-

larities of the current will be shown in its form. Hence the form of the current is spoken of, and expresses the consecutive variations in intensity. In Figs. 225 and 226 waves of various forms are shown. The dotted lines represent in each case separate waves of exactly the same length. The two dotted lines combined produce as a resultant in each case the heavy black line, which gives a third wave form.

Length of Wave and Frequency.—Waves of the same frequency are those which are produced the same number of times in a given period of time. The curves representing them are



FIGS. 225 AND 226.—WAVES OF DIFFERENT FORMS AND RESULTANT OF TWO WAVES.

drawn of the same length per wave if the waves are of the same frequency. In the diagrams of waves in this section of this book, the waves on each diagram are of the same frequency, and are therefore drawn of the same length.

Cause of the Form of Alternating Electromotive Force and Current.—The waves of current may vary in form, and the form depends upon the construction of the generator, with particular reference to the shape of the field-magnet pole pieces and of the armature core. The distribution of lines of force through the field may be varied indefinitely by changing the shape of the poles, even if the armature core is left unaltered. The current varies in intensity as the rate of change of the number of lines of force interlinked with the circuit varies. This rate of change de-

pends on the distribution of lines of force in the field. Hence any form, within reasonable limits, can be given to the alternating electromotive force and current waves. The form universally striven after is known as the sine curve.

Alternating Electromotive Force and Current Curves.—When an alternating electromotive force is producing a current, separate curves may be drawn for each. One zero or base line is used for both curves. The portions of the electromotive force curve above the line represent the portions of the electromotive force producing current represented by the portions of the current

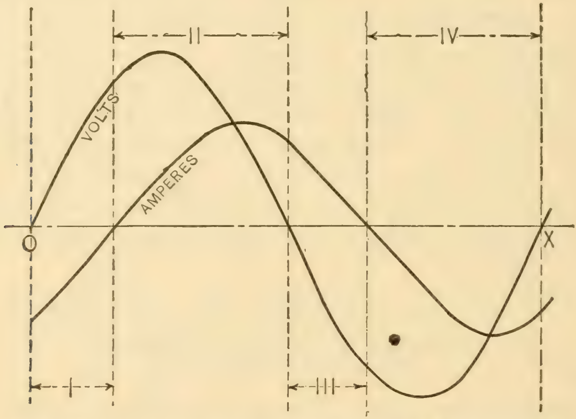


FIG. 227.—CURRENT AND ELECTROMOTIVE FORCE CURVES.

curve above the line. The same applies to the curves below the line. The length of a wave of current must be rigorously equal to that of a wave of electromotive force producing it. The height may be different, and as a matter of convenience usually is so drawn. Fig. 227 shows two such wave curves. The current curve may cross the zero line at the same points where the electromotive force current does, or may not, according to the conditions of the circuit. The single zero line or base line is the locus or place where current and electromotive force have zero value. When the current curve crosses this line, it indicates that the current at that instant ceases to exist. It is the point when it reverses

its direction, dropping to zero in one direction and starting in the other direction from zero. The same applies to alternating electromotive force and its polarity.

Drawing the Electromotive Force and Current Curves.—A straight horizontal line is drawn, and a portion of it is taken to represent the period of time taken by the system to produce one wave or cycle. For several reasons it is most convenient to divide this into periods of time, each equal to 1/360 of the period of a cycle or some integral divisor of 360, such 1/36 or 1/16. Suppose the line is divided into sixteen parts; at each a perpendicular is drawn. These are called ordinates of the curve. If electromotive force is the subject, each ordinate is drawn of length proportional to the voltage at the period it represents. For one polarity the ordinates are laid off upward, for the other polarity downward. Through their ends a line is drawn, and this represents the form of the cycle. The same method can be used for alternating-current curves, the lines being drawn of length proportional to the amperage of the current at different periods of the cycle. The method is illustrated in Fig. 224.

Degree System.—The portion of the zero line containing or subtending a complete wave, consisting of one positive and one negative portion, is by the degree system divided into the 360 divisions as described, each division representing one angular degree of rotation of a two-pole armature in a two-pole magnetic field. This armature may be only hypothetical. If the armature is four-pole and rotates in a four-pole field, each degree on the zero line of the current curve or electromotive force curve will represent one-half of a degree of its rotation; if it is a six-pole construction, one-third of a degree will be represented, and so on. Thus the ordinate at any point by the degree system can be referred to some point in the rotation of the rotor of the alternator. This indicates a reason for referring the divisions of the zero line to degree measurement. The form of the alternating current almost universally used in represented by the sine curve, and to make the construction of the curve intelligible and easy, the degree system is essential.

The Sine Curve.—The sine curve or curve of sines, as it is also called, is shown in Fig. 224, and is based on the following

principles: On a horizontal base line are erected perpendiculars. The line is divided into 360 parts, representing degrees of a circle. Each perpendicular is laid off equal in length to the sine of the angle expressed by the degree mark on which it stands. Up to the 180th division the perpendiculars are on one side of the base line; for the rest of the 360 divisions they are below it. The curve can also be drawn by the use of what is called the generating circle.

Generating Circle.—At one end of the horizontal zero line a circle, as in Fig. 224, is drawn, with its center on the line. Sines of various angles are drawn, and from the end of each sine a horizontal line is drawn, under or over the zero line, according to the position of the sines. The intersection of each horizontal line with a perpendicular to the base line erected on it at a point corresponding to the degrees of the arc of the sine gives a point on the sine curve. The arcs begin at the right-hand end of the horizontal diameter of the circle. Half of the sines are above and half below the base line, and the complete circumference of the circle gives the sines to determine the ordinates for one full cycle or wave. In the cut 22½° is the angle used in the construction.

The curve is drawn through the ends of the lines. The complete circumference of the circle gives one full wave.

An ellipse or various other figures or closed curves could be substituted for the circle, when other forms of waves would be produced. In practice the circle only is used, as the tendency of engineering is in the direction of the production of sine curve currents.

By reference to the generating circle, the sine curve may be thus simply described. Imagine the periphery of a circle straightened out so as to become a straight line. Mark upon it the degrees of the circle. Erect perpendiculars on each degree mark, for the first 180° above the line, for the rest below it, and make each line equal in length to the sine of the angle indicated by its degree mark. The curve is drawn through the ends of these lines.

The construction is shown in the cut, Fig. 224. The left-hand quadrant of the generating circle is divided into angles of 22½°,

or one-sixteenth of a circumference. For each angle sines are drawn, such as M P. On the base line divisions corresponding to the angles are laid off, and ordinates erected on them. Each sine determines the length of the ordinate corresponding to its angle. Thus, the sine M P of 45° determines the length of the ordinate M P erected on the second or 45° of the sixteen divisions of the horizontal base line.

Interpretation of the Generating Circle.—It is not necessary to draw a sine curve to represent the form of this universal type of alternating-current cycle. The cycle can be represented by the circle alone. Thus, the line drawn from the horizontal diameter, perpendicular to it, and intersecting the circle at any point, gives the value of the electromotive force or current at the instant represented by that point on the circle. This line at 90° has a maximum value. This means that when a period is one-quarter advanced from its beginning, the electromotive force or the current, as the case may be, has its maximum value. The same applies to the 270° of the circle. Values below the diameter are of polarity or direction opposite to that of values above it. At 180° the value of the perpendicular is zero, and after that it begins to increase in the opposite direction. This means that when the cycle is one-half completed, the electromotive force or current, as the case may be, has a value of zero, and immediately begins to increase, but in the opposite polarity or direction.

Rate of Change.—At the top or bottom of the loops the curve for two consecutive points is horizontal, where for an infinitely small period it moves parallel to the base line. Hence, if it represents current strength, the current for this instant will not change. Where the curve crosses the base line there is a place where the curve between two consecutive points is most steeply inclined to the horizontal line. At this place it approaches the vertical direction nearer than elsewhere, and at this place the electromotive force or current, whichever the curve represents, is changing most rapidly in value. It has here its highest rate of change.

Graphic Representation of Rate of Change.—If a radius sweeps through the arc of a quadrant, the successive sines will indicate the successive values of the alternating current it may

be taken as representing. As it starts from 0°, the sines will increase most rapidly in length and their rate of change will be greatest. As it approaches 90°, the sines will increase least rapidly in length for a given angular change, or their rate of change will be least. Let a second radius at 90° from the first be assumed to move around with the first one, always remaining perpendicular to it. The sines of the angles fixed by the positions of this second radius give the rate of change of current or electromotive force corresponding to the sine curve of the other or first radius. In Fig. 228 the two radii are shown, one marked R. of Ch. being the radius vector of rate of change.

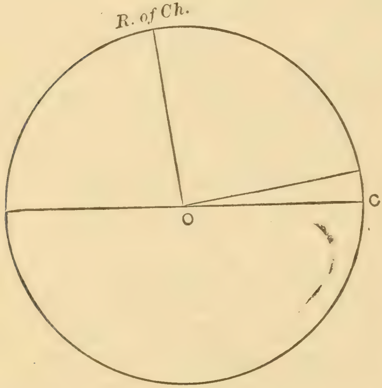


FIG. 228.—RADIUS VECTOR OF RATE OF CHANGE.

As a sine curve can be drawn from the first radius, a second one can be drawn from the other; the second sine curve will be a rate-of-change curve. The rate of change at any given point of the first curve will be proportional to the ordinate of the second curve at this point. The two curves will occupy fixed positions with reference to each other. They are said to be in quadrature with each other, as will be explained later. Fig. 232 may be referred to as showing two curves generated by radius vectors at right angles to each other.

Radius Vector and Resultant.—A line may be drawn from a common center or point called the origin, and may have two qualities. One is its length. This may be greater or less; and as the line is to be taken as representing a quantity, the length of the line must be proportional to the quantity it represents. This proportional size is determined by reference to some other line, otherwise the question of length would not come into consideration. The other quality is its angular position with refer-

ence to any other quantity, which quantity is taken as indicated by another line drawn from the origin as before. The angular position is the number of degrees included between the two lines.

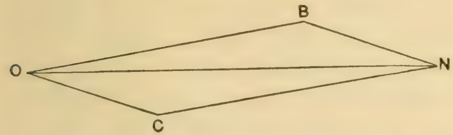


FIG. 229.—VECTORS AND RESULTANT.

Thus, suppose two quantities represented by two lines, Fig. 229, O B and O C, drawn from a common center at an angle with each other and one longer than the other. They would indicate two quantities out of phase with each other and one greater than the other. They would form two sides of a parallelogram, whose diagonal O N from the origin O outward would be their resultant, and would represent the combined effect of both quantities.

Vector Diagram of a Sine Curve.—From the center of a generating circle as shown in Fig. 230, radius vectors are drawn at equal angular distances around the circle. Each radius has marked upon it a point equal in distance from the center to the length of the sine of its angle. In the diagram, O Q is laid off on O P equal in length to the sine of 60°. The same is done for the other radius vectors, and a curve is drawn. For one-half of the wave this is a circle of half the diameter of the generating circle. Two circles one above and one below the zero line represent the full wave of a sine curve.

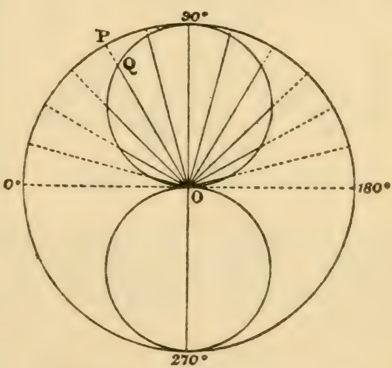


FIG 230.—VECTOR DIAGRAM OF SINE CURVE.

Phase, Lag, and Lead.—The length of a wave of impressed electromotive force is exactly equal to that of the wave of cur-

rent it produces. The waves also correspond in form, although in order to secure clearness in diagrams one set are often drawn of lower height than that of the other set. The two sets of waves may be in identical positions. This means that as each wave of electromotive force is impressed on the circuit, a corresponding wave of current accompanies it. At the instant when the electromotive force is greatest, the current would be greatest. Such waves are said to be in phase with each other, and are shown in Fig. 231.

In this and the following wave diagrams, the figures 1, 2, ... with the vertical lines enable the relations of the curves to be seen.

If the waves of alternating electromotive force take a certain

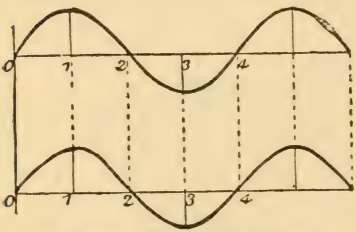


FIG. 231.—WAVES IN PHASE.

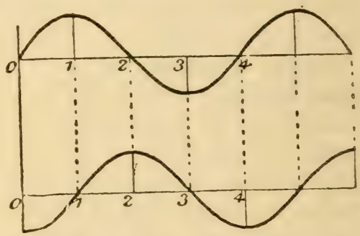


FIG. 232.—WAVES IN QUADRATURE.

time to produce the current waves, so that the current wave reaches its highest intensity after the electromotive force wave producing it has begun to diminish, the current waves are said to lag.

Such a condition is shown in diagram in Fig. 232 by the one set of waves lagging behind the other, crossing the zero line later than the others.

The reverse may hold. One set of waves may reach their height before the other set reaches it. They are said to lead, which condition Fig. 232 also serves to illustrate. Such condition is shown in diagram by the one set of waves reaching their highest points while the other set are still rising.

Angle of Lead and Lag.—We have seen that angular measurement can be applied to waves, and that the length of a wave is

360°. A fraction of the length of a wave is expressed in degrees. Half a wave is 180°, one-quarter of a wave is 90°, and so on. The difference in period between two waves is expressed therefore in degrees also. One set may lag 40° behind the other; as 40° is 1/9 of 360°, a lag of 40° means a lag of 1/9 of a wave length. The same applies to all lags and leads. The expression in degrees is called the angle of lag or of lead as the case may be. It is designated by θ.

Quadrature and Opposition.—If the angle of lag or of lead between two sets of waves is 90°, which is the quarter of a circle, the waves are said to be in quadrature with each other. The waves of Fig. 232 are in quadrature.

If the angle of lag or of lead is 180°, the waves are said to be in opposition, as shown in Fig. 233.

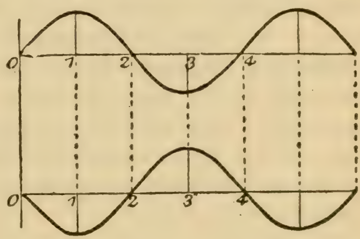


FIG. 233.—WAVES IN OPPOSITION.

Basis of Lag and Lead.—The waves of alternating electromotive force are the usual basis—the current waves are said to lag or lead. But if the current leads the electromotive force lags, and sometimes the current is employed as basis. A diagram of sine curves of two sets of waves, out of phase with each other, can be interpreted in two ways—as showing one set lagging or the other set leading.

Average Values.—The average intensity of a sine current is equal to the average of the sines. As half are positive and half are negative in value, the average value of the current is zero. This is more simply put if the current is simply thought of as alternating, half one way and half the other, and therefore as neutralizing itself.

This is begging the question. The thing that concerns the electrician is the practical value of the alternating current. It is a component of energy under proper conditions both coming and going.

The average value of the ordinates of a sine wave gives the average value of the thing it represents. It can be expressed

as a fraction of the longest of the vertical lines. By geometrical process it is proved to be equal to 0.63633 of the maximum ordinate, the longest of the vertical lines—it is nearly two-thirds of the line indicating the height of the crest. This figure is of little practical use, because what the engineer is concerned with is the power on his circuit. In the case of direct current, the product of electromotive force by amperes gives the power. Direct-current power plants operate either at constant potential or constant current, while the electromotive force and current are constantly varying in alternating-current distribution. The formulas for energy rate or power I E, $I^2 R$, and $\frac{E^2}{R}$ are given in a preceding section of this book. The two latter can be used for alternating current work, to get two of the factors for the power of the circuit—the effective electromotive force and effective current.

Effective Values.—The square of the value of a current is proportional to the watts it can produce in a conductor of definite resistance. The watt or volt-ampere is expressed by E I and by $I^2 R$ and the latter expression shows that with a fixed resistance the watts produced by a current vary with the square of the current.

The effective value of an alternating current is expressed as the intensity of a direct current which would with the same resistance develop the same number of watts. This current would produce the same quantity of heat with the same resistance. Doubling the current with the same resistance would give four times the heat.

The heating effect of an alternating current at any instant is proportional to the square of its intensity at that instant. The average of the squares of the values of the current through a half cycle is proportional to the average heating effect of the current. The square root of this average value is the effective value of the current.

Calculation of Effective Values.—Taking $I^2 R$ and $\frac{E^2}{R}$ as expressions for the rate of energy in a circuit, if the average value of the squares of current or of electromotive force be taken, it will give the expressions for average power. If the square

root of average I^2 or average E^2 be extracted, it will give what is known as the effective values of current and electromotive force. The effective value of an alternating quantity is defined as the square root of the mean square of the ordinates of the sine curve. The effective value is thus calculated.

Both the sines and cosines of the respective arcs of a quadrant vary exactly in the same ratio, but oppositely or complementarily disposed on all parts of a quadrant. We have the relation $\sin^2\theta + \cos^2\theta = 1$ if the radius is equal to unity. As the sine and cosine vary in the identical ratio, the average sine² is equal to the average cosine². Therefore from these considerations we have:

Average $\sin^2\theta +$ average $\cos^2\theta = 1$

Average $\sin^2\theta =$ average $\cos^2\theta$ disregarding the signs and only concerning ourselves with the numerical value.

$\therefore\ 2 \times$ average $\sin^2\theta = 1$

Average $\sin^2\theta = \frac{1}{2}$.

Average $\sin\theta = \sqrt{\frac{1}{2}} = \dfrac{1}{1.41+} = 0.7071.$

This gives us the factor used in obtaining the effective value of the thing shown by the sine curve. The effective value is then equal to the maximum value multiplied by 0.7071. The maximum value in the unitary circle is 1, and the formula is therefore applicable to other cases by substituting for 1 the value of the sin $90° \times$ radius $=$ radius.

Form Factor.—The quotient obtained by dividing the effective value by the mean value varies with the form of the curve. For a sine curve the value is $\dfrac{7\cdot7}{636} = 1.11$. This value is called the form factor.

This factor is of interest as giving the relative heating powers of alternating and direct currents. The alternating current will have about eleven per cent more heating power than will the direct current, which is of the same average strength.

If an alternating current voltmeter is placed upon a circuit in which the volts range from +100 to —100, it will read 70.7 volts, although the arithmetical average, irrespective of + or — sign, is really 63.7 volts. If a direct electromotive force were

to act upon the same instrument, it would have to be of 70.7 volts value, to give the same reading.

If an alternating sine current ammeter reads 100 amperes, it means that the current fluctuates from +141.4 to —141.4 amperes, but produces the same heating effect as if it were a 100-ampere direct current.

An interesting point to be made here is that if a generator is wound with two windings for alternating currents, its effective electromotive force will be 1.11 times higher than if operated as a direct-current dynamo, by commutator and proper connections. If wound with one open circuit of wire with two end connections to the collecting rings, its electromotive force will be 2.22 times higher.

The tendency of an electromotive force on a circuit to cause the piercing of the insulation depends on the maximum voltage. This voltage must be taken cognizance of for this and similar effects.

If on a Siemens dynamometer the current given by an alternator was found to be any given number of amperes, the maximum current would be found by dividing the reading by 0.707, or by multiplying by 1.41+.

Formulas for Effective Values.—The values can be expressed as vulgar fractions thus:

$$\text{Effective current} = \frac{\text{I max}}{\sqrt{2}}$$

$$\text{Effective electromotive force} = \frac{\text{E max}}{\sqrt{2}}$$

It will be noticed that in cases where the electromotive force or current intensity has been determined by an apparatus, it is always the effective values that are given by the readings of the instrument. As these are the working values, the coefficient 0.707 is of comparatively little use in practical working.

Power Factor.—The rate of energy or the power developed in a circuit by a direct current is expressed by E I. This will not answer for the alternating sine current. The periodic change in its values renders a constant necessary, with which the product of the effective current intensity by the effective electro-

motive force is multiplied to give the average power. This is a practical quantity; it is the cosine of the angle of lag, or cos φ.

$$\text{Average E I or power} = \frac{\text{E max I max}}{2} \cos \varphi.$$

Call effective current I, and effective electromotive force E. The equations for the effective values of current and electromotive force on page 330 give us the values of E max and I max, thus:

$$E = \frac{\text{E max}}{\sqrt{2}} \text{ or E max} = E. \sqrt{2}$$

$$I = \frac{\text{I max}}{\sqrt{2}} \text{ or I max} = I. \sqrt{2}$$

Substituting for E max and I max in the first equation their values as above, we have:

$$\text{Average E I or power} = \text{EI} \cos \varphi.$$

In this equation E and I are the effective values, such as would be determined by a voltmeter and ammeter adapted for alternating currents.

The factor cos φ is called the power factor.

Suppose the angle of lag is 90°, or that electromotive force and current are in quadrature with each other. In this case $\varphi = 90°$ and $\cos 90° = 0$. Therefore, the power factor being zero, the power when the current and electromotive force are in quadrature with each other is of zero value. This is the case of a wattless current.

A cosine has its greatest value, which is unity, when its angle is 0°. Therefore when $\varphi = 0$ the power is at its greatest, and is equal to the product of the effective values of electromotive force and current intensity. This case is when there is no lag of current, or when the current and electromotive force are in phase.

Qualities of a Circuit.—There are three qualities of a circuit which affect the action of alternating current and electromotive force upon it—resistance, inductance, and capacity. Each one has two effects—one effect upon the current, the other effect upon the phase relations of electromotive force and current.

Resistance acts to reduce alternating current, just as it does in the case of a direct current, in accordance with Ohm's law. This action upon an alternating current is greatest when the

current is greatest, as at the top of the wave, and is without effect when the current is zero, represented by the sine curve crossing the zero line; in other words, it has most effect when it has most material to work upon. Its second action is to tend to bring alternating current and alternating electromotive force into phase with each other.

Reactance.—The rate of alternating current which can pass through a circuit is modified by the resistance, inductance, and capacity in the circuit. The effects of each on the current can be indicated by ohms; the retarding effect of inductance and the reverse effect of capacity can be expressed in ohms, just as if they were resistance.

The ohmic values of capacity and inductance are called reactances—capacity reactance and induction reactance.

If the reactances and resistance of a circuit are known, its effect upon an alternating current is determined by Ohm's law subjected to certain modifications.

Inductance.—The relation of lines of force to current is induction. Current produced in a circuit by changes in the lines of force interlinked in it is induced current, and electromotive force so produced is said to be impressed on the circuit. The relations of lines of force produced by current in a circuit to that circuit constitute inductance or self-induction. As self-induction is due to changes in current intensity, it is an all-important thing in alternating current practice, where the current varies in intensity many times in a second.

Inductance in an alternating-current circuit acts to diminish or to absorb the electromotive force. It operates most when the current is at its zero value, because that is when the rate of change is greatest. This period is 90° removed from the period of maximum current, so that inductance acts in quadrature with resistance. Its second action is to cause the waves of current to lag behind those of the electromotive force.

Inductance and the Henry.—Energy is required to create a field of force, but not to maintain it. Conductors are related in their properties to the field of force established about them by a current, or in other words vary in their property of establishing fields of force under given current changes, which consti-

tutes this property called self-induction or inductance, and which is measured by a unit called the henry.

If a conductor is so constituted that a rate of change of current of one ampere per second in it requires the expenditure of one volt, it has an inductance of one henry.

The same thing may be stated otherwise. If the inductance of a circuit is such that a current increasing one ampere per second produces in it a counter electromotive force of one volt, the circuit has an inductance of one henry.

The henry is sometimes called the coefficient of inductance or of self-induction.

It is generally indicated by the letter L.

If the current in an active circuit decreases, the lines of force diminish and their potential energy becomes kinetic, and electromotive force increasing, the normal current is induced on the circuit.

Electromotive Force in an Alternating-Current Circuit.—The electromotive force in an alternating-current circuit containing inductance is partly expended in producing changes in the current. The electromotive force expended on increasing the current intensity varies with the rate of change. As the current increases, so also does the field density increase, and this increase of field density is what absorbs the energy indicated by the electromotive force multiplied by the current change. If the circumstances are such that the field diminishes in density, in so doing it generates electromotive force of the polarity corresponding to that producing the current to which the lines of force are due.

Counter Electromotive Force.—This is the hypothetical electromotive force opposed in polarity to the original impressed electromotive force, and due to inductance. It can only exist when the current is increasing in value. In an alternating-current circuit it appears when the current is increasing, and has the highest value when the current has the highest rate of change, which is when the current is passing from its period of zero value. It resists the action of impressed electromotive force, which produces an increasing current—that is to say, resists the current in the first and third quarters of a wave.

Forward Electromotive Force.—This is the hypothetical electromotive force of the same polarity as the original, and is also due to inductance. It can only exist when the current is diminishing in value, and has its highest value when the current is approaching zero value. It strengthens the action of impressed electromotive force which produces a diminishing current; it tends to increase the current in the second and fourth quarters of a wave when the impressed electromotive force would reduce it.

Counter and Forward Electromotive Force in an Alternating-Current Circuit.—From what has been said in the last two paragraphs, it will be seen that induced electromotive force in an alternating-current circuit, whether it be forward or counter electromotive force, opposes the action of the impressed electromotive force. When the latter is rising in value, its action is opposed by counter electromotive force; when it is falling in value, its action is opposed by forward electromotive force. Hence inductance generates for an alternating current what is virtually counter electromotive force for all its phases.

Turns of a Circuit and Inductance.—Assume a turn or convolution of a wire constituting a part of an electric circuit. If an ampere of current is passed through it, it constitutes an ampere turn. Let a current starting from zero value, and increasing to a definite value in one second, be passed through it. The lines of force of the field called into being will exercise inductance and produce a certain amount of counter electromotive force, which may be called e. Assume that a second convolution of wire is added, so that the current has to go through two turns, instead of one. As this gives double the ampere turns, twice as many lines of force will be called into existence during the second of growth of a current equal in all respects to the one assumed. Each turn of wire will therefore be impressed with counter electromotive force equal to $2e$, because twice the lines of force of the first case act upon it. But there are two turns, each acted on by counter electromotive force of $2e$. The total counter electromotive force is therefore $4e$. This gives the law:

The inductance of a circuit is proportional to the square of the number of its turns, if a constant rate of increase of current is maintained in it.

Reactance of Inductance.—A circuit opposes to the passage of an electric current, whether such current be constant or varying, a resistance. This is measured by the practical unit, ohm, and in alternating current topics is often called for precision's sake ohmic resistance. This is the resistance of Ohm's law, indicated in formulas by R, and is independent of the electromotive force and current.

Self-induction, which when a current is increasing in strength manifests itself by counter electromotive force, increases with the current and therefore with the electromotive force. Counter electromotive force is a variable quantity in a circuit of fixed inductance.

From Ohm's law expressed as $I = \frac{E}{R}$ we see that in a circuit of constant resistance the electromotive force must vary directly as the current. Therefore, as induced electromotive force varies directly with the current change, we can deduce an expression which will express it as a constant resistance, into which expression current will not enter as a factor. Then in the expression for the entire obstruction offered to an alternating or other type of varying current, we shall have two additive constituents. One is ohmic resistance, independent of current strength; the other is an ohmic equivalent of inductance, also independent of current strength.

Ohm's law can be expressed as $R = \frac{E}{I}$. The inductance of a circuit multiplied by the current change, which other things being equal varies with the ultimate current strength, is equal to the counter electromotive force. As these two factors increase and diminish together, counter electromotive force divided by current strength is a constant quantity. By Ohm's law $\frac{E}{I} = R$ or resistance. Hence we can express the effect of counter electromotive force on a varying current, which calls it into existence, by a constant resistance equivalent thereto in its action on such varying current.

This resistance can be expressed in ohms, and is called reactance.

By Ohm's law $R = \frac{E}{I}$. Therefore, $R = \frac{nE}{nI}$ where n is taken as any multiple whatever. But by the law of self-induction a rate of change in a current will produce a definite counter electromotive force in a specific circuit. If such rate of change be multiplied by a factor, which may be indicated by n, the electromotive force induced by it will also be increased in precisely the same ratio, or n times. Calling the rate of increase of current I or nI as the case may be, the induced electromotive force will be E and nE respectively, and $\frac{E}{I} = \frac{nE}{nI} = R$. Reactance is therefore expressible in ohms.

Ohmic Equivalent of Reactance of Inductance —This numerical quantity depends on two factors. One is the inductance in henries of the circuit, and the other is the frequency of the alternations of the current. Calling inductance in henries L and frequency f, we have the expression for the value of inductance reactance, A, in ohms:

$$A = 2\pi f L \text{ or } 6.28318\ f L$$

The numerical factor 6.28318 is 2π.

Inductance Reactance in Subdivided Conductor.—The inductance of a copper wire varies very little for variations in its diameter. In round numbers a wire of 167,000 circular mils cross section has 80 per cent of the inductance of one of 42,000 circular mils and 70 per cent of the inductance of one of 6,500 circular mils. The resistance in these three wires would be approximately in the ratio of 4 : 16 : 100, the inductance as 70 : 80 : 100. The resistance varying inversely with the circular mils, increases in a much greater ratio than the inductance, and the discrepancy increases in more rapid ratio as the conductors are reduced in size. With sufficient subdivision the ohmic resistance would incease in so rapid a ratio, that the inductance could be taken as constant without any considerable error.

Assume that inductance is unchanged by reducing the size of the conductor, and that we have a conductor of 1 ohm resistance, and at the given frequency of alternation possessing inductance whose effect is a reactance of 5 ohms. Assume that a current of 1 ampere is to be maintained.

The graphic solution is first given.

The perpendicular line, Fig. 234, is divided for ohms of resistance, the horizontal line for reactance, which is the ohmic equivalent of self-induction. The diagonal A indicates the impedance. Suppose we substitute four wires of the same aggregate section, then each wire will have a resistance of 4 ohms, and by our assumption the same inductance and consequent ohmic equivalent. The impedance of a single conductor will be shown by the line F. But this single conductor carries only one-fourth the current, or one-quarter am-

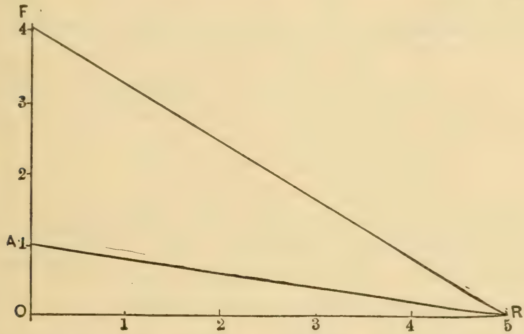


Fig. 234.—Reactance in Subdivided Conductor.

pere, because there are four of them. Its length represents the total impedance of one of the new lines, and evidently is not four times as long as A, but is but a small fraction greater. Therefore one of the new lines with an impedance of 6.04 ohms (for 6.04 is the length of R) has only one-fourth the current to carry that the original thick wire of impedance 5.1 ohms had to carry. The voltage drop in the thick line is by Ohm's law:

$$5.1 \times 1 = 5.1 \text{ volts.}$$

The voltage drop in one of the thin lines is:

$$6.04 \times \tfrac{1}{4} = 1.5 \text{ volts.}$$

But as the four thin lines are in parallel, there will be the same drop in each, or the subdivided main will carry the same current as the thick solid one at less than one-third the drop in potential.

The assumption made that self-inductance is the same for all

wires is incorrect, but the increase is so slow that the principle is correctly illustrated. If accurately calculated, the result will be a little less favorable to the subdivided line.

Capacity.—This is the third quality which may exist in an alternating-current circuit. It is the last of the three qualities spoken of on page 331. Its action upon alternating current is the reverse of that of inductance, as it reduces resistance and gives lead to the current. It is indicated by such diagrams as Fig. 235; inductance by such as Fig. 236; non-inductive resistance by such as Fig. 237.

Reactance of Capacity—If a condenser is connected in a cir-

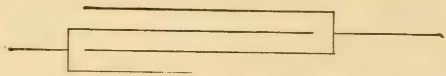


FIG. 235.—SYMBOL OF CAPACITY.

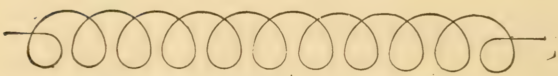


FIG. 236.—SYMBOL OF INDUCTANCE.

FIG. 237.—SYMBOL OF NON-INDUCTIVE RESISTANCE.

cuit, it will open or break the circuit as far as a direct current is concerned. No current would pass, and the circuit would be blocked as effectually as if the wire were cut. But the circuit with a condenser in it is a closed circuit for an alternating current. Electricity may be said to be poured into it at one period and out of it at another, so that the alternating action is kept up as if it were a closed circuit.

Just as resistance and inductance have each a twofold effect in an alternating current circuit, one upon the current intensity and the other on the phase relation of alternating current and electromotive force, so has capacity. Capacity increases current or reduces the resistance, or increases the conductivity of a cir-

cuit for alternating currents, and acts to give the current a lead over the electromotive force. Its action is exactly the reverse of that of inductance. Infinite inductance would reduce an alternating current to zero, while increase of capacity would diminish the reactance of a circuit so that an alternating current in it would be of increased strength.

Ohmic Equivalent of Reactance of Capacity.—It is best to use the farad as the unit of capacity in the reactance formula. Capacity appears in the formula as the denominator of a fraction, so that capacity reactance would become zero if capacity became infinite. The formula is in form the reciprocal of the inductance reactance formula, page 336, with farads, indicated by K, substituted for henries.

Calling farads of capacity K, and capacity reactance B, we have:

$$R = \frac{1}{2\ \pi\ f\,K} \text{ or } \frac{1}{6.28318\,f\,K}$$

This gives the value of capacity reactance in ohms for a current of frequency f with a capacity of K farads in its circuit.

Impedance indicates the impeding effect exercised upon an alternating current by the combined ohmic resistance and reactances of the circuit through which it passes. A circuit always contains resistance, and may contain capacity and inductance. If it contains two or three of these qualities, the ohmic resistance it offers to the passage of an alternating current is made up of the combined effect of resistance and reactance; the latter may be of one or of both kinds. The combined effect is not due to simple addition because induction reactance and capacity reactance are opposed to each other, and each is in quadrature with resistance.

Calling resistance R, inductance reactance A, and capacity reactance B, we have as the value of impedance:

$$\text{Impedance} = \sqrt{R^2 + (A - B)^2}$$

If there is no inductance reactance, then $A = 0$, and the above by regular algebraic process reduces to $\sqrt{R^2 + B^2}$.

If there is no capacity reactance, then $B = 0$, and it reduces to $\sqrt{R^2 + A^2}$.

Electric Resonance.—This term is applied to the condition that obtains in a circuit when the inductance reactance, expressed

by $2\pi f L$, and the capacity reactance, expressed by $\frac{1}{2\pi f K}$, are equal to each other. The formula for the impedance of a circuit containing resistance inductance and capacity is:

$$\text{Impedance} = \sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f K}\right)^2}$$

If $2\pi f L = \frac{1}{2\pi f K}$ then the formula reduces to:

$$\text{Impedance} = \sqrt{R^2} \text{ or } R.$$

Electrical resonance in other words causes an alternating-current circuit to act as if it had only true ohmic resistance. But its capacity and inductance have not been annihilated, but only put into opposition with each other, and this brings about resonance.

By Ohm's law we have E = R I. For the inductance of a circuit the Ohmic equivalent of reactance must be substituted in the above formula. Then the value of I is determined by Ohm's law as if there were neither inductance nor reactance, and with that value of I, and substituting for R the ohmic value of inductance reactance or capacity reactance, the value of E for the inductance element and capacity element of the system are reached.

Suppose that in a system fed by alternating current there is a condenser of 50 microfarads capacity (0.00005 farad) and that there is an inductance of 0.050 henry. Take the frequency at 100 and the effective E.M.F. as 100 volts. The inductance reactance is $2\pi \times 100 \times 0.050 = 31.4$; the capacity reactance is

$\frac{1}{2\pi \times 100 \times 0.00005} = \frac{1}{0.0314} = 31.8$. Take the resistance at 2 ohms. Then for the total impedance we have: Impedance = $\sqrt{2^2 + (31.4 - 31.8)^2}$ which is practically 2 ohms. By Ohm's law a current will flow through such a circuit expressed by: $\frac{E}{R}$ or $\frac{100}{2} = 50$ amperes.

Neither of the reactances has been annihilated; they simply counteract each other's effects, but each acts individually the same as ever. The inductance reactance remains at 32 ohms nearly. Through it a current of 50 ohms has to pass. Therefore by Ohm's

law, $E = I R$, we have $E = 50 \times 32$ or 1600 volts as the electromotive force between the terminals of the coil embodying the inductance of the system. For the reactance an identical figure is obtained. Thus by resonance an original 100-volt electromotive force can generate in parts of a circuit a voltage many times greater. Fig. 238 shows the diagram of a portion of a circuit containing inductance and capacity.

All the figures in the above calculation are approximate, decimals being omitted or restricted.

The equation $2 \pi f L = \frac{1}{2 \pi f K}$ may be considered as expressing the condition of resonancy. It follows that if f and L are known, the value of K which gives resonancy can be calculated, and that if f and K are known, the corresponding value of L can be calculated. This is done by the ordinary operations of algebra. The equation tells that if L is large K must be small, and *vice versa*, in order to bring about resonance.

In a circuit in which electrical resonance exists the entire circuit is not affected by it, but only the portions containing inductance and capacity. The circuit as a whole passes the current subject to Ohm's law, while the portion containing inductance and the other portion containing capacity work in concert with each other, and if in tune, as it is sometimes expressed, are the seats of high electromotive force. Damage to apparatus sometimes ensues from this. While resonance eliminates the effects of the inductance and the capacity upon the circuit taken as a whole, it leaves each one unaffected in its action. The inductance still has its value in henries, the capacity still has its value in farads, and they retain their individual characteristics and power of reaction.

Causes of Lag and Lead.—The effect of inductance in a circuit is to cause alternating current to lag behind the impressed alternating electromotive force which produces it. The lag, if the circuit possessed neither capacity nor resistance, would attain its highest possible value, which is 90° or quadrature. Inductance is the cause of lag.

The effect of resistance in a circuit is to cause alternating current to tend to be in phase with the impressed electromotive

force. If a circuit possessed neither capacity nor inductance, the impressed electromotive force and current would be in perfect phase with each other.

The effect of capacity in a circuit is to cause the current to lead impressed alternating electromotive force. This lead, if the circuit possessed neither inductance nor resistance, would attain its highest possible value, which, as in the case of lag above cited, is 90°, or quadrature. Capacity is the cause of lead.

It follows that resistance acts in quadrature with inductance and capacity, and that capacity acts in direct opposition to inductance.

Summation of Alternating Quantities.—The combined effect of quantities acting additively in alternating manner, so that their alternations may be represented by a sine curve, cannot

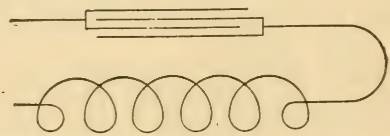


FIG. 238.—CAPACITY AND INDUCTANCE IN A CIRCUIT.

always be expressed by simple addition. Suppose a sine wave one inch high represents the action of a certain alternating current. Next suppose that a second current is poured into the line, coinciding in phase, intensity, and form with the first. A wave of twice the height would result. The combined effects of the two currents could be expressed numerically by adding them together.

It will be understood that whatever is said of current here applies also to electromotive force. Current and electromotive force alternate in exactly the same manner, and either can have its action represented by a curve of the sine type.

Suppose now that the currents differed 180° in phase, as shown in Fig. 233. One would be positive in its alternation when the other was negative, one would exactly counteract the other, and the result would be zero. Suppose that the phases of the two currents differ 90° in phase. In some parts of their cycles they

co-operate, in others they resist each other, and a more complicated curve is the result.

The values of two sine curves can be added together by drawing them and constructing a new curve. Its height at any point is determined by adding algebraically the heights of the original curves at that point. Distances below the base line are treated as negative. Fig. 239 shows another method. A F and A F′ are the generating circles of two sine waves whose phase difference is the angle between A B and A B′. The two vectors are compounded as in Fig. 239, and with the new vector A B″ a new generating circle is produced, from which the new curve is generated. The curve

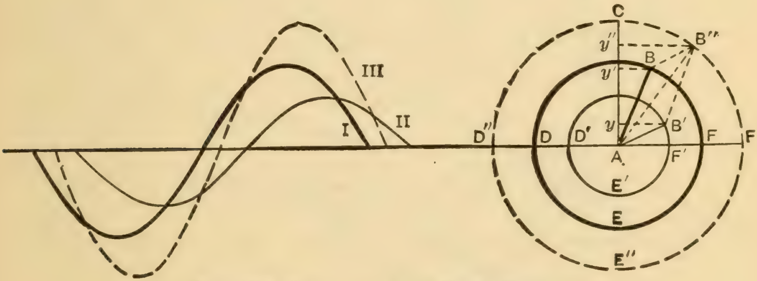


FIG. 239.—SUMMATION OF SINE CURVES.

I is generated from circle F B D E, curve II from circle F′ . . . , and the curve III is produced by adding I and II or by directly generating it from the generating circle B″. . .

Composition of Resistance, Inductance, and Capacity.—Every circuit possesses these three qualities. Their combined effect may be found by a simple diagram, although where accuracy is required, mathematical calculations are essential.

Let a horizontal line be drawn starting at an origin O and of length to represent the ohmic resistance of a circuit. The reactance of inductance will be represented by a line at right angles to it, because the two are in quadrature. Draw the inductance line vertical and rising from the origin, and of length to represent inductance reactance. The reactance of capacity is 180° removed from that of inductance, and hence is also in quadrature

with resistance. The line representing it will start from the origin and extend vertically downward.

There is nothing absolute about the position of these lines, except that they must be related to each other as shown.

Each line or radius vector must be drawn of length to give the relative value in ohms of the reactance it represents.

In the diagram, Fig. 239*a*, the line O R represents resistance, O I represents inductance, and O K capacity. Draw I D parallel to O R and equal to it in length. The diagonal from O to D or O D is the resultant of combined effect of resistance and inductance reactance. Then from D draw a line D F parallel to O K and equal to it in length. The diagonal O F will give a line expressing the combined effect of the two reactances and of resistance.

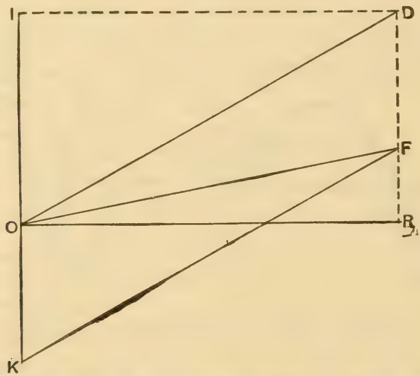


FIG. 239*a*.—COMPOSITION OF RESISTANCE, INDUCTANCE, AND CAPACITY.

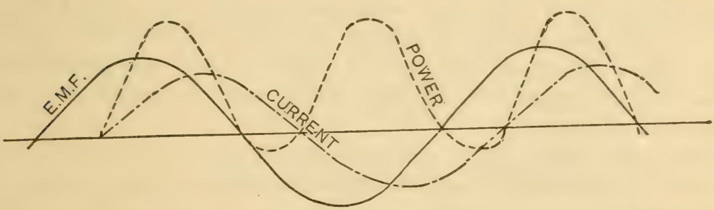
Multiplication of Alternating Quantities.—The multiplication of alternating quantities has to be done to find the power of a circuit in watts, because the latter unit is a product of electromotive force by current, a volt by an ampere. The term volt-ampere signifies a watt.

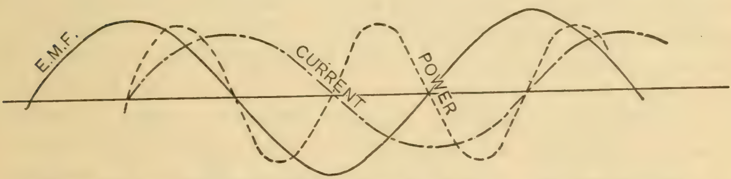
If an alternating electromotive force is multiplied by an alternating current, a product differing altogether in form and value from the additive or compounded result is obtained. This

product is a curve of power, of volt-amperes or of watts. Its amplitudes indicate quantities of watts at the different periods.

Power Curves.—The diagrams, Figs. 240 and 241, show each a curve of sines of electromotive force in full line, and one of current in dots. Multiplying their amplitudes together, new amplitudes are obtained, which give the curve drawn in dot and dash, which is the volt-ampere curve, curve of watts or power curve.

When the current curve or the electromotive force curve crosses





FIGS. 240 AND 241.—MULTIPLICATION OF ALTERNATING QUANTITIES.

the base line, its amplitude is zero. Therefore the amplitude of the power curve at this point must also be zero, because the product of a finite quantity, in this case the amplitude of the other curve at the same point, multiplied by zero is equal to zero. As the electromotive force is, in the case shown in the cut, out of phase with the current, for each cycle or period there are four zero factors. This brings the power curve twice as often to the base line as either of the original curves. It has twice the alternations of either of them.

The system receives energy from the alternator during the time the power curve is above the base line. It receives energy in varying amounts whose measure is the amplitude of the curve at that point. It returns energy to the alternator when below

the line, measured as before for any instant by the amplitude of the curve at that point.

The second of these diagrams, Fig. 241, shows the electromotive force curve and current curve in quadrature with each other. This condition would be brought about by presence of inductance and absence of resistance in the circuit. The power curve in this case is half above and half below the line. It has twice the alternations of either of the other curves, just as before. It indicates the return of exactly as much energy as is received. In such a case no energy is expended on the line. It is the case of the wattless current. The portions of the curve above the line represent power received; those below represent power returned. The two are equal, and as they are opposed in action, the combined result is zero.

Referring again to Fig. 227, the current and electromotive force curves are divided by vertical lines crossing the zero line at the intersections of the curves. Within the space I, E. M. F. ordinates above the line, which are positive, are multiplied by current ordinates below it, which are negative. The result is negative by algebra. Therefore the new curve for this division is below the line and negative. Within the space II, positive E. M. F. ordinates are multiplied by positive current ordinates, giving a positive curve or one above the line. Within the space III, positive current ordinates are multiplied by negative E. M. F. ordinates, bringing the combined curve below the line. Within the space IV, both current and E. M. F. ordinates are negative. But by algebra negative multiplied by negative gives a positive quantity; therefore the combined curve is above the line here. This result is shown in Fig. 240.

If E. M. F. and current curves are in phase with each other, all the multiplications are either of positive by positive or negative by negative, so that the new power curve is all on the positive side of the zero line.

Two-Phase Current.—If two electromotive forces invariably in quadrature with each other are simultaneously produced by a generator, the currents produced may be distributed over four conductors, a pair for each current. The combination is called a two-phase current. It is illustrated in diagram, Fig. 242. The

full line A... is one current, the dotted line B... is the other; the 90° distances are marked on the diagram.

Three-Phase Current.—If three electromotive forces invari-

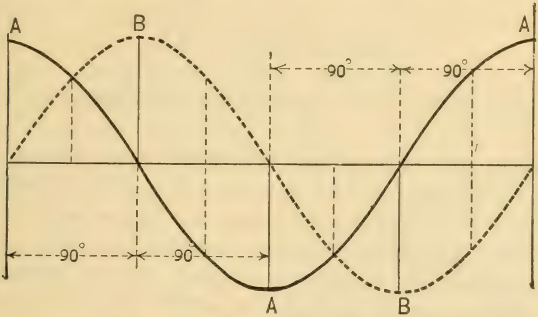


FIG. 242.—TWO-PHASE CURRENT.

ably 120° apart in phase are impressed on a six-wire circuit, what is called a three-phase current results. By special connections this current can be distributed by means of three or of four

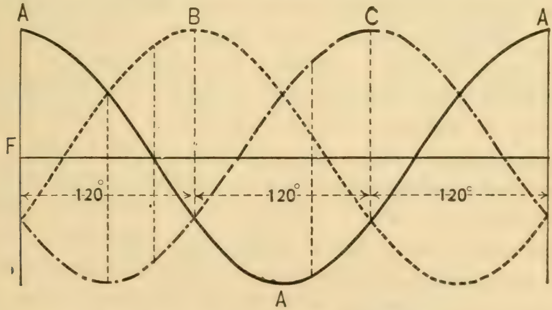


FIG. 243.—THREE-PHASE CURRENT.

wires. The diagram, Fig. 243, illustrates it. The full line A..., dotted line B..., and dot and dash line C... are curves of the three currents which really make up the so-called three-phase current.

CHAPTER XX.

ALTERNATING CURRENT GENERATORS.

Generation of Alternating Current.—Alternating current is generated in dynamo-electric generators, which represent one of the simplest or fundamental cases of impressment of electromotive force. The direct current dynamo is a step in the direction of complication, as the alternating current dynamo with its simple collecting rings taking the current as it is generated is the simplest of all mechanical generators. For this reason some authors treat of alternating generators first and then of direct current generators. Some even make a discussion of the alternating current lead up to the direct current.

Single-Phase Armature.—If a coil of wire with disconnected ends is rotated in a magnetic field with its axis of rotation symmetrically placed as regards the lines of force, it will have impressed upon it at each revolution two electromotive forces of opposite polarity. Its position may be to a considerable degree unsymmetrical as regards the field of force, yet the same will be true. Electromotive force to be utilized must produce a current. To utilize these pulsations, the ends of the open-circuit coil must be connected by an outer circuit. Upon the shaft carrying the coil are secured two copper rings insulated from one another and from the shaft. One terminal of the rotating coil is connected to one ring, and the other terminal to the other ring. A pair of brushes bear against the rings, one brush for each ring, and to these brushes the terminals of the outer circuit are connected. One terminal is connected to each brush, and the brushes are insulated from the frame of the machine. An iron core is placed within the coil, as in the direct-current dynamo, so that an armature is constituted.

The electromotive force produced by the rotation of the coil is

proportionate to the rate of change of the number of lines of force interlinked with the circuit by means of the coil. The electromotive force passes from a maximum of one polarity to a value of zero, then to a maximum of the other polarity, back to zero, and then to its original polarity. This varying electromotive force tends to produce upon the closed circuit a current varying in like manner as regards intensity, and reversing in direction as the polarity of the electromotive force changes. The reversing in direction of current must occur exactly as often as the reversing in polarity of the electromotive force, but lag or

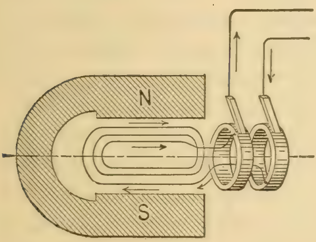


FIG. 244.—ELEMENTARY ONE-PHASE ALTERNATOR.

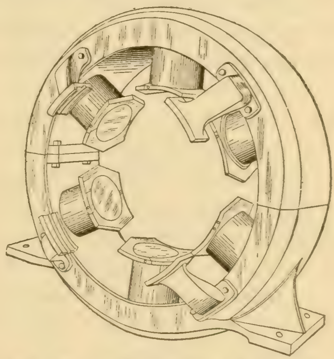


FIG. 245.—MULTIPOLAR STATOR.

lead will generally operate to prevent the two being simultaneous, as they would be if there were no inductance or capacity in the circuit.

The diagram of such a dynamo is given in Fig. 244. It is the simplest possible representation of an alternating-current generator. The object and function of an alternating-current generator are to impress alternating electromotive force upon a circuit. What disposition is made of that electromotive force, whether it is made to produce a corresponding alternating current or not, and if it produces one how near it is to be to that which should be exacted by Ohm's law—all these are questions outside of the operation of the dynamo, except as regards its unvarying factors, such as capacity, inductance, and ohmic resistance.

Such an armature would produce a single alternating current on a closed circuit, and such a current is called a single-phase current.

Multipolar Construction.—The alternating current as used in modern engineering practice must be of high frequency. A complete cycle would, with the bipolar construction just described, require a complete revolution. To give high frequency the armature would have to be rotated at very high speed. If the poles are increased in number, a single rotation will give more cycles; in typical constructions one cycle is given per revolution for each pair of poles. If the field contains four poles, there will be two cycles per rotation; if it contains six poles, there will be three cycles, and so on. By increasing the number of poles a given frequency is obtained with fewer rotations of the armature per second. For this reason alternate-current generators generally have a number of poles, bipolar construction not being much used. Generators with more than two field poles are called multipolar generators, and a multipolar stator is shown in Fig. 245.

Grouping of Windings.—The windings in alternators are generally referable to groupings. The active conductors may generally be assigned to groups, each group of approximately the width occupied by the face of a field pole, and there being a group of conductors for each pole. In a general way multipolar construction by filling the circle of the armature with pole faces tends to make the distribution of conductors on the armature periphery even, but grouping can always be traced out for them.

Principle of Alternate-Current Armature Winding.—This principle is that all active portions of the winding of an individual armature winding must coincide in action at each instant, all co-operating to produce the same effect on the circuit. The direct-current armature winding with its commutator works in parallel of two for each pair of poles, while the alternating-current armature winding operates in series whatever is the number of field poles. The active conductors of an alternate current winding must be so joined that at any instant an electromotive force of uniform polarity shall be impressed upon all of them.

Drum Armature Connections.—Suppose any number of pairs of north and south field poles arranged symmetrically around a

drum-armature core, mounted in bearings. Let the cylindrical surface of the core have conductors insulated from each other secured to it. If rotated in the multipolar field, each conductor will have alternating impulses of electromotive force impressed upon it, as many in one revolution as there are poles in the field, and changing in polarization or "direction", in one revolution also as many times as the number of poles.

Elementary Four-Pole Single-Phase Armature.—In Fig. 246 a core is shown upon whose surface four conductors are placed. If rotated in a four-pole field, electromotive force will be impressed upon them of opposite polarity for every alternate conductor. The ends of these conductors are to be connected by wires or other conductors extending across the front and rear ends of the armature core. The arrowheads indicate the polarity of the electromotive force, or the direction of current which it tends to produce in each conductor, at the instant indicated. To have these currents coincide in direction for the entire winding, the front end of one conductor must be connected to the front end of a conductor one pole removed from it; the rear end of this one connected to the rear end of a conductor one pole removed from it in the same direction, and the same system is carried out all around the circle. This brings the two ends of the windings out together. One end is connected to one collecting ring, the other is connected to the second collecting ring. Such a winding will give a single-phase alternating current. The action may be described as a zigzag action. The terminals of the winding are subjected to the accumulated electromotive force impressed on the active conductors by the four poles of the field.

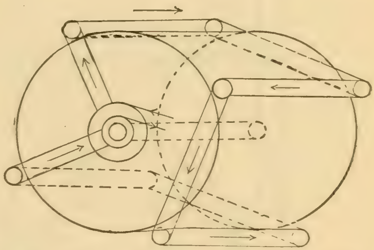


FIG. 246.- ELEMENTARY ONE-PHASE DRUM ARMATURE WOUND FOR A FOUR-POLE FIELD.

Single-Phase Wave and Lap Winding.—An example of wave winding is shown in Fig. 247 in development. It will be seen

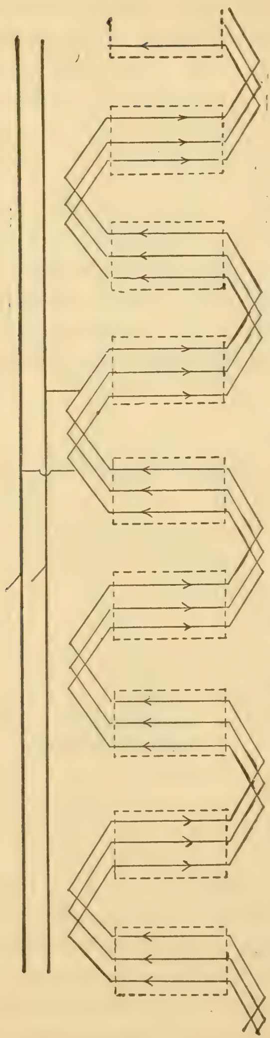


FIG. 247.—SINGLE-PHASE ALTERNATING CURRENT WAVE WINDING.

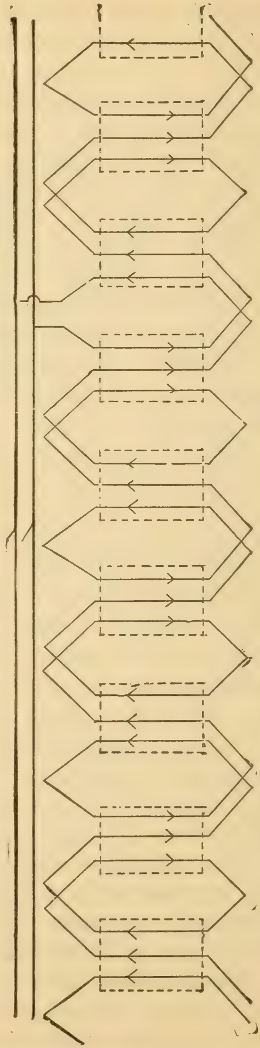


FIG. 248.—SINGLE-PHASE ALTERNATING CURRENT LAP WINDING.

that the electromotive force impressed on each active conductor of the armature co-operates to produce a current in one direction

all through the windings. The active wires are spaced in accordance with the distance from pole to pole. In direct-current winding the spacing is usually a little more or a little less than this distance.

The next cut, Fig. 248, shows in development a single-phase lap winding. The spacing is regulated as in wave winding by the distance from pole to pole, and a uniform impressing of electromotive force on all the active conductors is produced.

If we trace the course of the conductors in two successive loops in the direct-current lap winding, we shall find our course a series of left-handed or right-handed turns as the case may be,

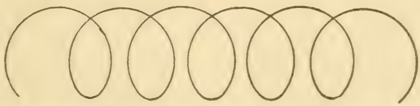


FIG. 249.—ANALYSIS OF DIRECT CURRENT LAP WINDING.

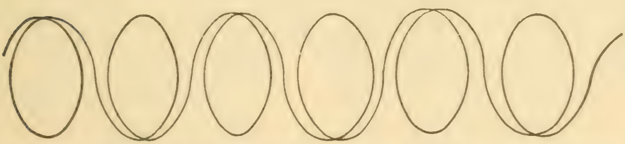


FIG. 250.—ANALYSIS OF ALTERNATING CURRENT LAP WINDING.

but either left-handed or right-handed all the way around. If we start in the lines of Fig. 143 at the left hand and follow the line beginning at the left, we shall progress in a sort of spiral toward the right hand, always in the same sense. In this particular case it will be against the movement of the hands of a watch.

If the alternate current lap winding, Fig. 248, is traced out through its loops, we shall progress with the hands of a clock in one loop and against the hands of a clock in the next loop all the way around.

The courses followed can be roughly shown, as in Figs. 249 and 250.

Ring Winding for Alternating Current.—In Fig. 251 is shown how a Gramme ring armature can be made to give an alternating

current. For each pole of the field a single lead is taken from equidistant parts of the windings. Every second connection is taken to one collecting ring, and the others to the other collecting ring. Such an armature rotated in a multipolar field whose number of evenly-spaced poles is equal to the ring connections will develop a single-phase alternating current. The connections operate to divide the windings into groups, one for each pole.

Conventional Representation of Collecting Rings.—In Fig.

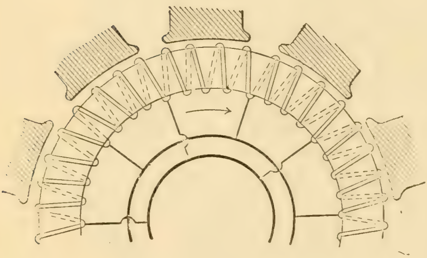


FIG 251.—GRAMME RING CONNECTED FOR SINGLE-PHASE ALTERNATING CURRENT.

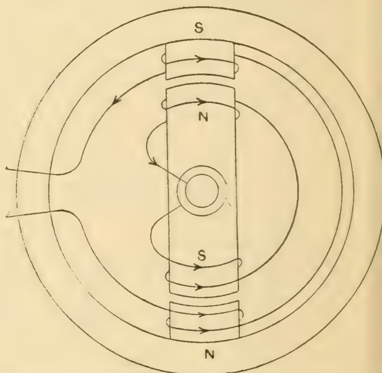


FIG. 252.—BIPOLAR SINGLE-PHASE ALTERNATING CURRENT POLE GENERATOR.

251 we see the conventional way of representing collecting rings in diagrams. Two circles are drawn from the same center. One is of greater diameter than the other, and each represents a ring. These rings are really of identical size, but are conventionally represented as of different size, in order to distinguish between them.

Pole Single-Phase Armature.—Armatures for alternating currents are sometimes of the projecting-pole type. Poles project radially from them, and are wound in the same sense as the poles of the field. A direct current passed through the windings of such an armature would cause one projecting pole to be of

north polarity and the next one to be of south polarity. One consecutive winding goes around all the poles in succession, and the induced single-phase current is taken from its terminals.

In Fig. 252 direct current from an outside source may pass through the windings of the poles attached to the frame. The armature rotated in the field thus formed delivers current to the circuit connected to the collecting rings. The reverse may be carried out. Direct current may be supplied to the central poles by connections to the brushes. If the central part is rotated, alternating current can be taken from the windings of the frame poles. This construction would give one cycle per revolution.

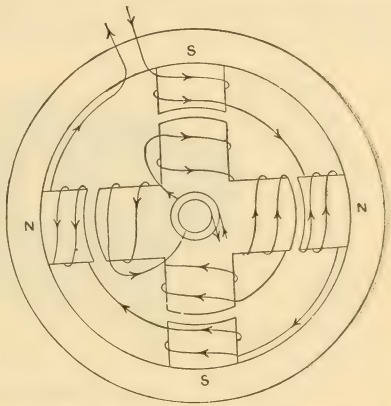


FIG. 253.—FOUR-POLE SINGLE-PHASE ALTERNATING CURRENT GENERATOR.

In Fig. 253 the same system is indicated for four poles. This construction would give two cycles per revolution.

Rotor and Stator.—In both the examples shown in the diagram, Figs. 252 and 253, electromotive force could be impressed on either the stationary or rotary member of the machine. Whichever part it is impressed on is the armature. The approved terminology for alternators calls the part which turns the rotor, whether it is a revolving field or armature; and calls the part which does not turn the stator, whether it is a stationary armature or field. Yet the distinction of field and armature remains. The alternator can always show two parts, one the field through which a direct current is passed, the other the armature on whose windings alternating electromotive force is impressed. Either may be rotor.

The general rule for single-phase windings is that armature and field are interchangeable. If a direct current is supplied to the field, electromotive force will be impressed on the armature as the rotor turns. Again, if the armature be supplied

with direct current, the field will have electromotive force impressed upon its windings. There is nothing practical in this, because the armature and field are generally wound with widely-different sizes and lengths of wires. One is wound to have good excitation from the source of direct current. The other is wound to give alternating electromotive force of the desired number of volts, under the effects of the field. It is obvious that the windings are apt to be widely different.

Inductor Alternator.—The principles of this type of alternator are shown in Fig. 254. The stator is both armature and field. The full line indicates the field winding through which a direct

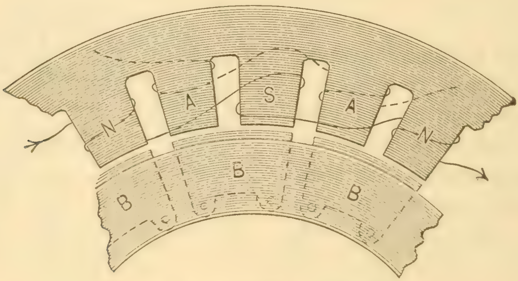


FIG. 254.—INDUCTOR ALTERNATOR.

current is maintained. It is wound around every second pole, so as to excite north and south polarity in them alternately. Thus, taking a north pole as a starting point, the one next to it would be without polarity, because the field windings do not go around it. The next pole would be a south pole, owing to the direction of the winding. This succession is kept up all the way around. A segment only is shown in the cut. The full line indicates the field winding, and the field poles are marked N and S. The neutral poles between the field poles are marked A A, and the armature winding on them is shown by the dotted line. It is wound in the reverse sense on neighboring poles.

The rotor carries heavy masses of soft iron B B', called inductors, each one wide enough to cover two poles on the stator and the interval between them. As the rotor turns, it changes the

polarity of the neutral poles. Thus in the position shown, the left-hand neutral pole, acted on by the inductor extending from it to the south pole on its right, is polarized with north polarity. The right-hand inductor polarizes the right-hand neutral pole above it with south polarity. When the rotor turns through an angular distance equal to one pole face and one pole interval, the opposite polarities are imparted to the neutral poles. In each revolution of the rotor the armature poles vary in polarity as many times as there are poles in the stator.

The great advantage of this type of machine is that the windings are stationary. A machine with rapidly-rotating rotor carrying windings with it is not so solid a construction as one in which the carefully insulated windings are on a motionless part of the machine.

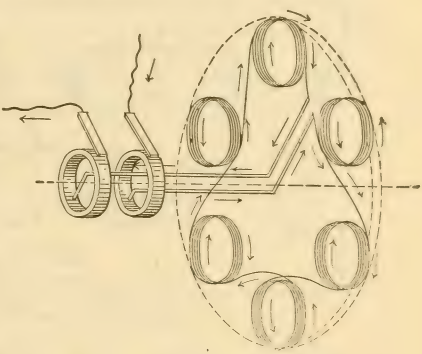


FIG. 255.—WINDING OF DISK ARMATURE FOR SINGLE-PHASE A. C. CURRENTS.

Disk Windings.—This kind of armature has been used extensively in Europe, but not very extensively in this country. In preceding pages 305, Figs. 203 and 205, disk dynamos have been shown, and in Fig. 255 the coils and collecting ring connections of a disk armature are shown. The arrows indicate the directon of the current. This direction changes during a rotation six times, because the armature is wound for a six-pole field. The disk armature does not need an iron core; it is so thin that the lines of force readily strike across it from pole to pole.

Two-Phase Winding.—Suppose it was desired to send out two independent currents of equal periodicity, but differing as regards the phases of the electromotive force producing them, one electromotive force to be 90° behind the other. Two independent machines could be mechanically coupled. This would have to be so effected that the proper phase relation would obtain,

which would involve setting the armatures so that one would be one half of a pole interval behind the other. The currents could be distributed on four lines of wire, two to each machine. The phase relation existing between the electromotive forces on the two circuits being invariable, the result would be called a two-phase current. An easier way to produce it is to have a second independent winding on the same armature. A single machine then produces the two-phase current.

The cut, Fig. 256, shows the principle. The conductors A A

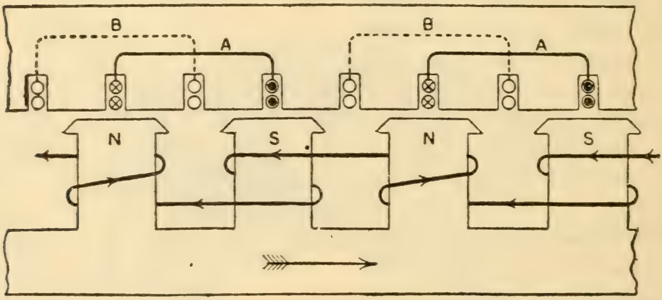


FIG. 256.—TWO-PHASE WINDING.

are parts of a continuous conductor that goes all around the armature in every second groove. The windings B B do the same. The ends of each winding go to their own pair of collecting rings, of which there are four. The diagram shows rotor and stator as straight; in reality, each one is circular, and one lies within the other in the regular way.

In the position shown, the windings A A are being acted on, and the current in them is indicated by the dot and cross symbols—the dots indicating current coming toward the observer, and the crosses indicating current going away from him. The conductors B B in the position shown have no electromotive force impressed on them; their sine curve is crossing the zero line.

Either part shown can be stator. Usually it would be the armature.

Three-Phase Winding.—What has been said of the two-phase

winding may be repeated with slight variation of three-phase winding as shown in Fig. 257. The three windings are designated by A, B, and C, and as no winding is in a neutral position, dots and crosses are put on all. The three represent three independent windings, and may deliver current to six collecting rings, a pair for each winding.

Corresponding parts of adjacent windings are distant from each other two-thirds of a pole interval or one-third of two poles, which for a bipolar machine would be 120°. This fixes the condition

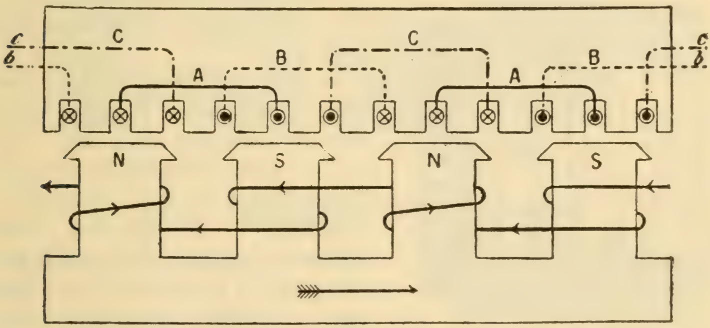


FIG. 257.—THREE-PHASE WINDING.

that the currents induced shall be 120° different in phase from each other.

Six-Wire Connection of Three-Phase Alternator Winding.—The windings of a three-phase alternator may be variously connected. They may be treated as if they were windings of three separate machines, in which case two conductors would be assigned to each of the three outer circuits which they could supply. This would give a total of six conductors to be led through the district. Almost always other systems are used, which enable the distribution to be effected with three or four wires. A six-ring collector system is shown in Fig. 258.

Y or Star Connection.—This connection requires four wires to distribute the power from a three-phase alternator—three active and one neutral wires. The latter passes current when the balance is disturbed, exactly like the neutral wire in the three-wire

system of parallel distribution. The connections are made in the machine and on the outer circuit.

The three windings of a three-phase alternator can be taken as beginning at three adjacent points on the armature. From these points collector-ring connections would be made were the six-wire system in use. For the Y system three of these ends, symmetrically distributed with reference to each other, are connected together, and one lead is taken from them through the district, which is the neutral lead. From each of the other ends of the three windings a lead is taken, thus giving a total of four leads.

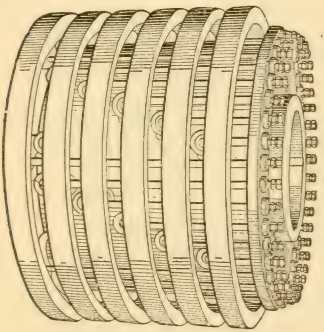


FIG. 258.—SIX-RING COLLECTOR FOR ALTERNATOR.

In the utilizing of the four mains, each lamp or other appliance is connected from one of the active wires to the neutral wire. The balance is kept as true as possible by taking the same amount of power from each active lead. If exactly the same amount is taken, the neutral wire carries no current.

The development of a Y winding is shown in Fig. 259. There are three windings, A, B, and C. The A winding begins at A_1 and ends at A_4; the B winding begins at B_1 and ends at B_4; the C winding begins at B_1 and ends at B_4. The six ends which might be connected to six independent line wires are A, B, C, A_4, B_4, and C_4. For the Y connection each second end is connected to the neutral wire. In the development these alternate ends are A_1, C_1, and B_4. The remaining ends A_4, C_4, B_1 are connected each to one of the active wires. If the course of the current is examined by the rule given on page 210, and carried out in Fig. 259 by the arrowheads, it will be seen that a strong downward current in A_1 is balanced by weaker upward currents in B_4 and C_1. The relative strength of the currents is due to the strength of the field through which they are moving, and A_1 is evidently in a stronger field than either B_4 or C_1. A strong current goes upward to the

upper line, which line indicates a collector ring with brush A, while weaker currents go down from the other collector rings.

Delta or Mesh Connection.—Taking the three windings as before, a first and last end can be assigned to each. Thus in the

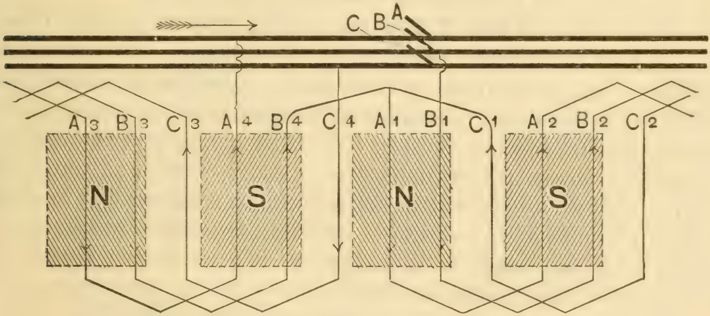
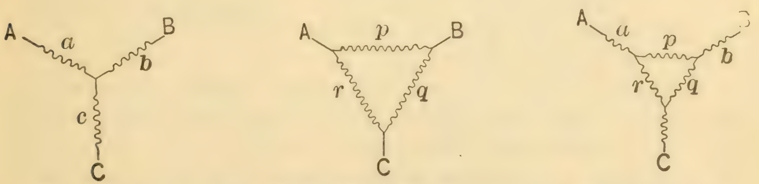


FIG. 259.—DEVELOPMENT OF Y CONNECTIONS.

Y connection it may be taken that the three interconnected ends joined to the neutral wire are first ends, and the three ends with separate conductors are the last ends. For delta connection the three windings are joined in series. The last end of one winding is joined to the first end of the winding next to it in phase (120°



FIGS. 260, 261, AND 262.—Y, DELTA, AND COMBINATION CONNECTIONS.

removed in phase). The last end of this second winding is joined to the first end of the third winding, and the last end of the third winding is joined to the first end of the first winding. From each junction of first and last ends a wire is led through the district which is to be supplied, a total of three wires, there being no neutral wire.

Line Connections.—The appliances on the line may be connected from wire to wire, so as to maintain the delta distribution over the working circuit, or the Y system may be used with a delta system at its junction, so as to dispense with a neutral wire. The Y connection is shown in Fig. 260, the delta connection in Fig. 261, and the combined Y and delta connection in Fig. 262.

Neutral Wire in the Y System.—This wire is usually treated as a part of the system requisite to its operation. It can be suppressed if the appliances on the three divisions are evenly balanced, the case being precisely analogous to that of the neutral wire in the three-wire system of distribution, except that it is a case of one neutral wire for three active wires and not of one neutral for two active wires. It is obviously impossible to secure such distribution in ordinary practice, so that naturally the fourth wire has come to be regarded as a necessary part of the connections. An interesting illustration of the properties of the Y connection has been made by causing three carbons to take the place of the three limbs of the Y and producing an arc at the junction, the carbons being drawn apart, as to cause a triple arc to strike. It was maintained without any neutral wire. Another experiment was the lighting of a triple-filament lamp, three leading-in wires connecting to filaments joined at their ends Y fashion. This lamp was ignited without any return wire.

CHAPTER XXI.

ALTERNATING CURRENT MOTORS.

The Induction Motor.—This is a motor whose action depends upon the induction of electro-magnetic polarity in an armature wound with a re-entrant coil, or with a coil whose members are connected in parallel. The coil must not be an open one. The alternating current in the field induces currents in the windings, which induced currents produce polarity in the core of the armature. The polarity of the armature being due only to induction, gives its name to the motor.

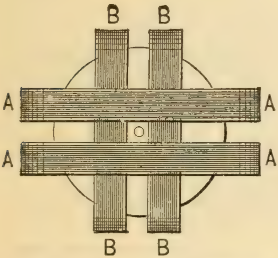


FIG. 263.—ROTARY FIELD COILS.

The Rotary Field.—The production of the rotary field is the principal reason for the generation of polyphase currents. By means of this invisible transferring of magnetic polarity around a circle, one principal type of the alternating-current motor is operated.

The cut, Fig. 263, shows four coils of wire. Let the coils B B receive an alternating current, while the coils A A receive another current in quadrature with the first. The result will be that when the current in B B is at its maximum, the current A A.. will be of zero intensity. Then as the current in B.. decreases, that in A... will increase. When the B current is at its maximum, north and south magnet poles will be established on a horizontal axis passing through the center of the B coils. The A coils when active will establish poles on an axis perpendicular thereto. Poles at intermediate points will be established when current is passing through all four coils. The result of the arrangement is that

a north and south pole are kept traveling around the circle by the action of the alternating currents in quadrature with each other. Such currents constitute a two-phase alternating current.

The change of one current from one maximum to the other takes place perhaps one hundred times in a second. Hence the resultant poles of the field whirl around it with great rapidity. The first Niagara alternators give a two-phase current with twenty-five periods in a second. These produce a rotating field that has fifteen hundred rotations per minute.

Three such coils of wire with a three-phase current would give a rotary field.

Magnetic Needle in a Rotating Field.—A compass needle pivoted in the rotating field with its axis of suspension coinciding with the axis of rotation of the field would whirl around with the speed of the field once it was started. Such an arrangement would not be an induction motor. An induction motor is one in which the rotating field induces currents in the armature, and under the combined effect of the field and armature excitation the armature revolves.

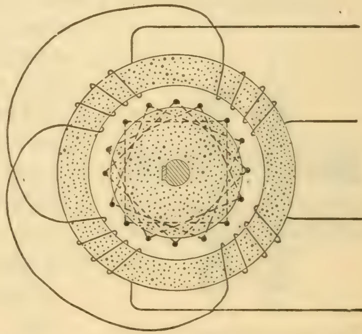


FIG. 264.—TWO-PHASE ROTATING FIELD AND ARMATURE.

Armature in a Rotary Field.—If instead of a magnetic needle a cylindrical laminated armature core wound with a re-entrant coil as shown in Fig. 264 is mounted on bearings in the field, it will rotate. This it will do because the alternating currents will induce currents in its wires. This they do directly by their rotary field of force. This whirls around, and thus its lines of force are cut by the windings of the armature core, which cutting induces a current in them, producing north and south poles in the core. The core with its windings is mounted in journals and rotates as did the magnetized needle, but with a very important distinction. To establish in the core the polarity

described above, lines of force have to be cut by its windings. Therefore it drops behind in its revolutions, and turns from one to five per cent, ten per cent in small motors at full load, slower than does the rotary field. If it by any means was made to synchronize with the field, it would have no induced polarity such as described, and no pull or torque would be exerted upon it. Therefore it constantly falls behind. The amount of this falling behind is called its slip.

The generation of a three-phase current and the operation by it of an induction motor are shown in diagram in Fig. 265. By

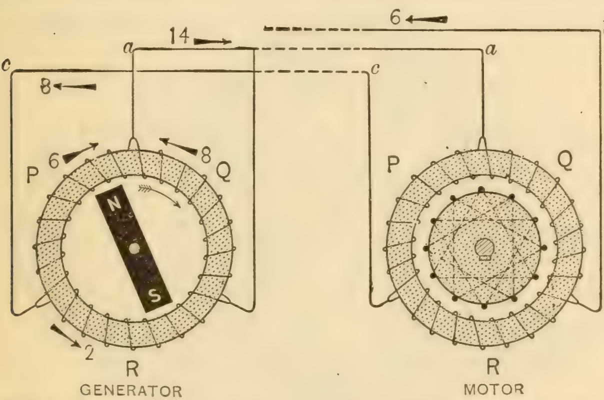


FIG. 265.—THREE-PHASE GENERATOR AND INDUCTION MOTOR.

following the figures it will be seen that the stator of the motor receives the identical currents induced in the stator of the generator; but the poles of the generator stator travel around it. Consequently, a rotary field is produced in the stator of the motor.

Three-Phase Induction Motor.—The diagram, Fig. 266, represents a four-pole three-phase generator driving such a motor. The generator has twelve armature coils, three sets marked A B C for each field pole, giving a three-phase current. They are connected in Y combination. The left-hand diagram represents the generator. The field is the rotor. The motor, also with twelve

coils, marked as in the motor, and Y-connected, is indicated by the right-hand diagram. The motor and generator are connected by three wires, *a*, *b* and *c*. The fourth wire is omitted because it would have no load to carry. The capital letters on the armature of the generator enable the course of the windings to be followed.

The three-phase current produces a rotary field as the two-phase current does on the same general principle. The lag of the currents behind one another acts to cause the poles resulting from the combined action of the coils to rotate around the field. These poles may be the resultant of two or of three windings; they are never due to one only in the three-phase motor.

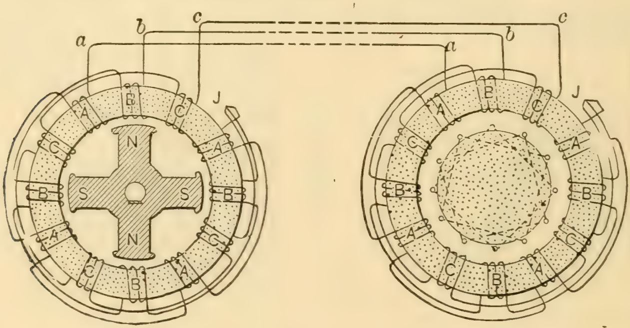


FIG. 266.—FOUR-POLE THREE-PHASE GENERATOR AND INDUCTION MOTOR.

Induction Motors.—Motors constructed on the above principle are called induction motors. One of the most striking features about them is the fact that the coils on the armature, which is the rotor, are self-contained, have their terminals connected so that the winding is purely re-entrant, and have no outside connection whatever. A General Electric Company induction motor is shown in Fig. 267.

Rotary and Revolving Field.—What has been described is the rotary field. In it the rotary action is purely electrical, there is no rotation of any part of the mechanism. A revolving field is another thing—it is a field which turns around an axis like a wheel. It is often used in alternating-current generators. There

is danger of confusion in the use of these two terms, and the meaning of each should be grasped, so as to keep the distinction between them.

By a simple modification of mechanical structure, a rotary field may be mounted on journals and the armature may be fixed. In such a case the field becomes the rotor, and is really a combined rotary and revolving field.

Starting Torque.—Polyphase-current induction motors have a starting torque, which single-phase synchronous motors are destitute of. This feature has made polyphase currents the favorite type of alternating currents.

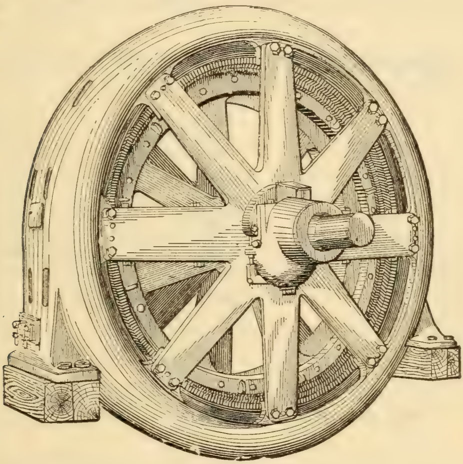


FIG. 267.—INDUCTION MOTOR WITH SQUIRREL CAGE ARMATURE.

Squirrel Cage Armature.—This is a favorite type of armature used on induction motors. It consists of a laminated core, with straight conductors of copper lying in longitudinal grooves or holes as close to its surface as possible. The ends are connected to two rings of copper. The windings thus provided have been aptly compared to a squirrel cage, and the name has been definitely adopted for them. A simple form is shown in Fig. 268.

Starting Resistances are used to develop starting torque. It

is proved in the analytical discussion of the induction motor that at starting the torque is proportional to the rotor resistance. Resistances are provided for changing the resistance of the rotor windings. In the General Electric Company's form L motor, a wound armature is used with distinct circuits instead of a squirrel-cage armature. The terminals of the circuits come out in the center of the armature, and are connected to each other through resistance grids. The grids have contact points, and a shoe worked from outside the motor by a lever slides back and forth, so as to cut resistance in or out as required.

Many arrangements of starting resistance have been used by different makers.

Starting Compensator.—This is also used in starting the in-

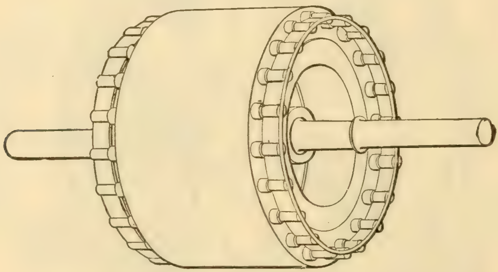


FIG. 268.—SQUIRREL CAGE ARMATURE.

duction motor. It is a transformer containing a single coil which takes full line voltage. It has one or more taps, and by connecting the motor to one of the taps a reduced voltage is obtained for starting. When the motor reaches nearly full speed, it is thrown from the tap directly into the circuit, so as to get full voltage. The change is effected by a switch working in oil situated in the base of the compensator. The motor to be used with this apparatus has the simple squirrel-cage armature, as there is no change of armature resistance to be brought about, and it is of simpler construction. It is applicable where the motor is not obliged to start with full load, and where there is no objection to the use of a large starting current.

Lenz's Law and the Induction Motor.—Lenz's law applies to this motor. The rotary field as its poles move induces currents in the armature opposing the motion of the fields. This motion while not mechanical has exactly the effect of a mechanical movement of the poles. Currents opposing the motion, with their action increased by the iron of the core, cause the armature to rotate exactly in accordance with the law.

Construction of Induction Motors.—Laminated cores for field and armature are much used, such as have already been illustrated previously. The windings of the armature, if of the squirrel-cage type, are not necessarily insulated from the frame. The motor with starting resistance may give a starting torque 50 per cent greater than the full load running torque with about the same excess of current. They are made of high horse-power as well as of smaller power.

The Synchronous Motor.—If two single-phase alternators are connected together in one circuit, one may be driven by power so as to impress alternating electromotive force upon the line with accompanying current. The other alternator receiving current from the line if it is once started into motion so as to correspond with the alternations of the other, will continue moving and be a motor. For each alternation of current an identical alternation is involved in its operation; the two machines working together harmonize exactly in the time of their alternations, and are said to be in synchronism. The motor machine is a synchronous motor.

When current and electromotive force generated by its motion harmonize in direction, an electric machine of the dynamo type in which such condition exists is a generator. In other words, such condition can only exist in a system to which power is applied—can only exist in a dynamo whose armature is turned by power. If mechanical energy is expended on an alternator, electromotive force and current harmonizing with each other will be the result.

The generation of electromotive force opposed to the current received by a dynamo indicates that that dynamo is a motor—is giving out no electrical energy, but is absorbing it and is giving out mechanical energy. Therefore, if an alternator has its cur-

rent opposed to the electromotive force its motion generates, it becomes under proper conditions a motor.

The synchronous one-phase motor is based on these principles.

Condition of Operation.—The cut, Fig. 269, shows two curves, one of electromotive force, and one of current. The current lags. The current and electromotive force oppose each other in the section marked I, are together in II, opposed in III, and together in IV. An alternator producing a current and electromotive force of these relations would during the periods I and III give out mechanical energy and absorb electric energy and

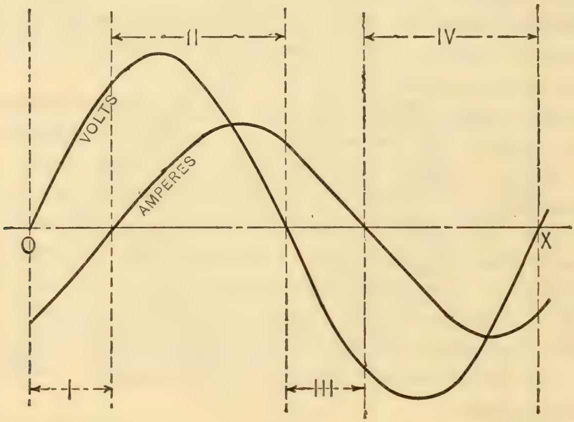


FIG. 269.—CURRENT AND ELECTROMOTIVE FORCE CURVES.

be a motor. During the periods II and IV it would absorb mechanical energy and give out electric energy and be a generator.

If the lag was 90°, or in quadrature, the periods I and III would be equal in all ways to II and IV, and the machine as far as its electrical functions were concerned would absorb no mechanical energy and give out no electrical energy. It would be in a wattless condition. If the lag exceeded 90°, periods I and III would be larger than II and IV, and the machine would absorb electric energy and give off mechanical energy and would become a synchronous motor.

There need be no structural difference between the generator of a single-phase alternating current and the synchronous motor driven by it. Whether a machine is one or the other is a question of phase relation of volts and amperes. If the two identical machines of the single-phase alternating-current type are connected electrically, and one is rotated by power as a generator and the other by any means is caused to rotate at the same speed, the latter becomes a motor, and will thereafter rotate at the identical speed of the generator and be driven by it as a synchronous motor. In the generator the electromotive force and current will be nearly in phase with each other. In the

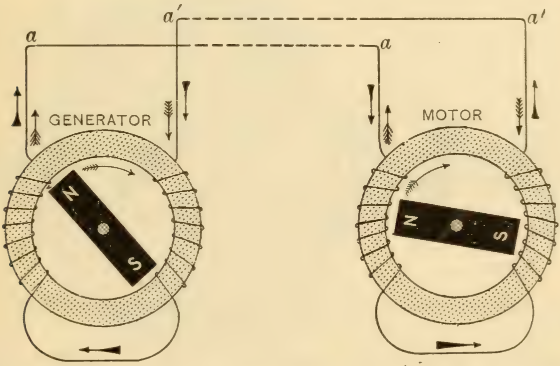


FIG. 270.—SINGLE-PHASE GENERATOR AND SYNCHRONOUS MOTOR.

motor counter electromotive force will be generated, and will almost exactly oppose the current. In the generator the curves of current and electromotive force will be almost in phase, and in the motor the counter electromotive force will be almost 180° different in phase.

Single-Phase Synchronous Motor.—A single-phase generator and motor connected are shown in the diagram, Fig. 270. They are of identical construction. The current generated by the generator is indicated by the heavy arrows. This current causes the rotor of the motor to turn in exact synchronism with the generator. The rotation of the rotor of the motor generates

counter electromotive force. The polarity of this is indicated by the lighter arrows.

For synchronous rotation the conditions of phase in the two armatures must be exactly opposite, if one is to be a generator and one a motor. Therefore, torque is not to be looked for until synchronism is attained. For this reason a synchronous single-phase motor has no starting torque, and has to be started in some way until it moves as fast as the generator. After that is done it will go on exercising torque, and absorbing electrical and developing mechanical energy.

To start it the current is divided, and one branch by a capacity

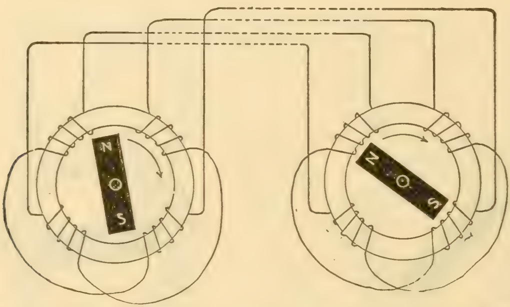


FIG. 271.—THREE-PHASE GENERATOR AND SYNCHRONOUS MOTOR.

or inductance is thrown as nearly 90° out of phase with the other as possible. The two leads are then connected to the machine and establish a rotary field, and the synchronous motor is thus converted into an induction motor. It is speeded up, as it now has starting torque. When going fast enough the inductance is cut out, and it continues in motion as a synchronous motor.

Synchronous Polyphase Motor.—As far as revolving is concerned, a polyphase generator and motor may be identical. In a rotating field magnet permanent poles are maintained by a direct current. The polyphase alternating current is passed through the windings of a stationary armature. This creates in it a rotary field. The condition is illustrated in diagram in Fig. 271, a permanent magnet representing the electro-magnet of the description. The generator on the left produces a rotary

field in the motor, which causes its rotor, which is its field magnet, to revolve in exact synchronism.

The stator and rotor may be reversed in the construction.

Self-Starting Synchronous Motor.—To make a polyphase synchronous motor self-starting, the following arrangement is sometimes adopted.

Copper bars connected at their ends are bedded in the faces of the pole pieces of the field magnet. The rotary field acts upon these, and induces current in them exactly as in the induction motor. To start the motor, the direct-current field circuit is opened, and the alternating circuit is closed. The motor is now an

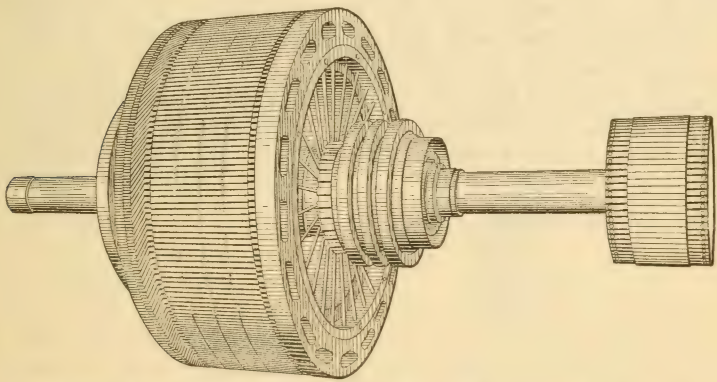


FIG. 272.– SYNCHRONOUS MOTOR ROTOR WITH STARTING ARMATURE.

induction motor, and the rotor begins to turn. It is given no load, so that the rotor soon turns almost at the speed of the rotary field. The direct current is now turned on, and the motor becomes a synchronous motor. The elements of the induction motor are still present, but no torque is exercised by them because there is no slip.

The same principle is carried out by mounting on the same shaft with the synchronous armature a smaller induction-motor armature. When in place each armature lies in its own field, and the induction motor is used to start and to bring up to synchronism the larger armature of the synchronous motor. When

this is effected, the synchronous motor takes up the load, and the induction motor ceases to act. Fig. 272 shows the armature of a synchronous motor with the squirrel-cage armature of the starting induction motor on the right-hand end of the shaft.

In the above lines the use of direct current and of alternating current for the motor has been spoken of. This refers to the field and armature currents respectively. An alternating-current generator has its field excited by a direct current, and generates an alternating current from its armature. An alternating current synchronous motor goes a step further, as it has to be connected to two distinct circuits for its operation, each one supplying power. One circuit possesses direct current, which excites the field; the latter may be rotor or stator. In the diagrams it is shown as the rotor, and to avoid complication a permanent magnet is used as its representative. The other circuit, entirely distinct from the first one mentioned, passes alternating current to the armature windings. This is the true power circuit, current from which actuates the machine. In the diagrams the armature is shown as the stator, but the relation of stator and rotor can be changed.

CHAPTER XXII.

TRANSFORMERS.

Basis of Transformer Construction.—If a current passes through a conductor, it establishes around it a field of force. Energy is expended in producing the field, but none in maintaining it. If a second wire or conductor lies parallel to the first during the time that the field of force is being built up, electromotive force will be impressed upon it by the growth in number of the lines of force. This electromotive force will be of such polarity that it will tend to produce a current in the opposite direction to the original current. If the other current weakens, energy will be drawn away from the field, and the electromotive force impressed upon the neighboring wire will be of the reverse polarity. Current is only produced during the period of change of intensity of field. The transformer contains two coils of wire insulated from each other. One, the primary, receives varying electromotive force; the other, which is the secondary, has electromotive force impressed upon it by variations in the current passing through the primary.

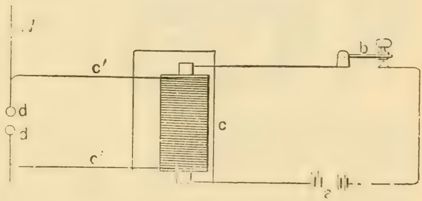


FIG. 273.—ACTION OF A TRANSFORMER.

In Fig. 273 C represents a bundle of iron wire wound with two coils of insulated wire. The circuit from one coil, which is of small relative length and large current capacity, contains a battery *a* and key *b*. The other coil of long fine wire has on its outer circuit *c′ c′* two electrodes *d d*. On depressing and releasing the key, a spark will jump across the air space between the two

electrodes, if all proportions are right. The first-named coil is the primary; the other is the secondary.

The Object of a Transformer is to receive a given alternating voltage from an alternator delivered at one pair of terminals, and to deliver at another pair of terminals a different alternating voltage. The transformers seen on house fronts and power line poles may have a comparatively fine wire deliver a small current at 1,000 to 6,000 volts potential to their primary terminals, while from their secondary terminals a current twenty to one hundred or more times greater is taken off with a potential difference at the secondary terminals of 50 or 60 volts only.

A small copper wire might thus deliver a 1¼-ampere current to a transformer with 6,000 volts between the primary terminals.

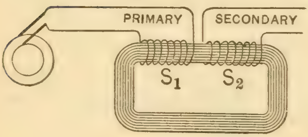


FIG. 274.—ALTERNATOR AND CONVERTER RELATIONS.

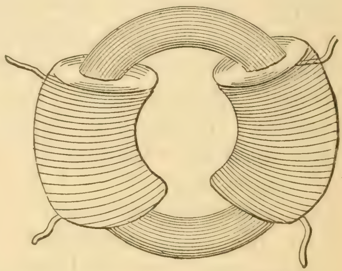


FIG. 274*a*.—RING TRANSFORMER.

This would be about 10 horse-power. But if this 10 horse-power had to be delivered with only 50 volts potential difference between the primary terminals, the wire would have had to be of twelve times the cross-sectional area, and consequently of twelve times the weight, and approximately twelve times the cost.

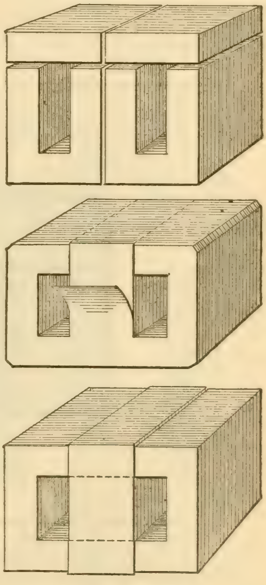
Choking.—Another function is performed by transformers. The current passed through them between their primary terminals is almost nothing if none is taken from the secondary. Hence they act to "choke" or hold back the current when desired without any considerable ensuing loss of energy.

The construction is simplicity itself. The apparatus is so simple and efficient that it appeals to the electrician as one of the most perfect of all electrical appliances. There are no moving

parts to wear out, except in a special type of transformer, and its action is absolutely automatic and perfect.

Sylvanus P. Thompson very aptly says that a transformer may be regarded as a dynamo with stationary field and armature, in which the alternating magnetism of the iron coil induces the desired current in the secondary coil, representing the armature.

The Limitation of a Transformer is that it has to have a varying current; practically, it is used only on alternating current circuits. It produces a secondary alternating current, which can be made to give a direct one by special mechanism.



FIGS. 275, 276, AND 277.—LAMINATED SHELL TYPE TRANSFORMER CORES.

The Principle of a Transformer is shown in diagram in Fig. 274. An alternating current from an alternator on the left goes through the primary coil, which is wound around a sort of iron ring. Another coil entirely disconnected from the primary is also wound around the ring; this is called the secondary coil. A ring transformer with adequate coils is shown in Fig. 274*a*. As current goes back and forth in the primary, it produces lines of force, in the iron core principally. As the current starting from zero increases to a maximum, the lines of force increase in number, and are of polarity corresponding to the direction of the current. As the current recedes to zero the lines of force die away, and as the current goes to a maximum in the reverse direction, lines of force of opposite polarity to the first are produced. These changes in intensity and polarity of the field impress upon the secondary an electromotive force varying from zero to maximum, and of constantly changing polarity. If there are ten times as many turns of wire in the primary as there are in the secondary, the electromotive

force impressed on the secondary will be one-tenth that in the primary coil. The direct proportion of voltage impressed to relative number of turns will hold for all ordinary conditions.

Shell or Jacket Type Transformers are those in which the coils are surrounded by masses of laminated iron. The material of the cores has to be of metal of good quality and quite thin. Insulation of some kind is used between the plates out of which the core is built up.

The cuts, Figs. 275, 276, and 277, show the construction of mod-

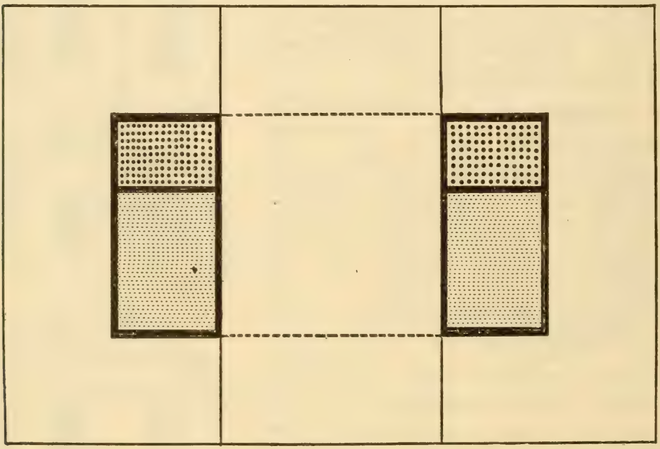


FIG. 278 —SECTION OF A SHELL TYPE TRANSFORMER.

ern transformer cores, which are built up from the plates after the coils have been wound upon a form. The plates in the example shown are cut in such a shape that they can be pushed into the openings of the coils.

The primary and secondary coils can be wound on top of each other or side by side. The cuts, Figs. 278 and 280, show the coils on top of each other.

Step-Up and Step-Down Transformers.—If the transformer raises the voltage of a system, it is called a step-up transformer; if it lowers it, its more usual service, it is called a step-down transformer or a transformer without any qualification.

Ratio of Transformation.—The ratio of voltage impressed on the primary to that impressed on the secondary in the working of the transformer, as determined by the relative numbers of turns of wire in each, is called the ratio of transformation. It is expressed by a fraction $\frac{\text{secondary turns}}{\text{primary turns}}$ and is often designated by k.

Shell Type Transformers.—The construction of the working

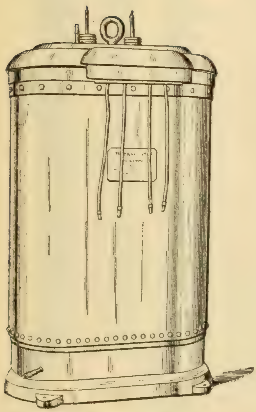


FIG. 279.—SHELL TYPE TRANSFORMER.

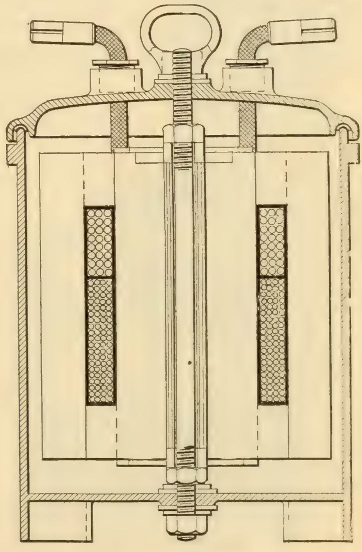


FIG. 280.—SECTION OF SHELL TYPE TRANSFORMER.

parts of a typical shell type transformer is shown in Figs. 279 and 280 in section and elevation. The apparatus is a transformer of the shell or jacket type, so called because a hollow laminated mass of iron, electrically speaking its core, surrounds the coils of the transformer. In the section the coils are seen imbedded in the hollow core. In this particular coil, the coils primary and secondary are wound separately and placed one above the other.

Another shell type transformer with coils partly exposed is shown in Fig. 281.

Core Transformers.—Transformers whose core is surrounded by the insulated primary and secondary coils are thus named. In Figs. 282 and others such coils are shown. In Fig. 283 the construction of such a transformer is shown, and in the next cuts, Figs. 284 and 285, another form is illustrated. The ring transformers shown in Figs. 274 and 274*a* are really core type transformers, although the term is usually applied

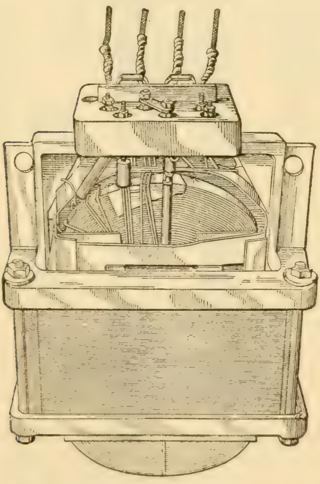


FIG. 281.—SHELL TYPE TRANSFORMER.

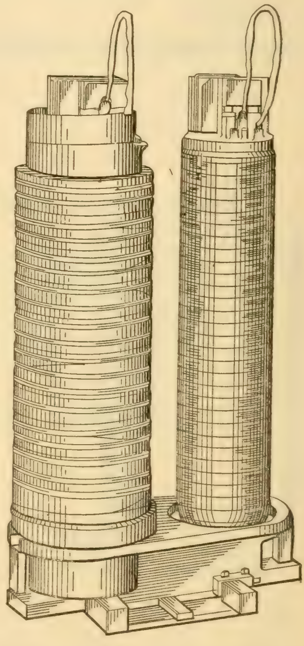


FIG. 282.—CORES OF CORE TYPE OIL-COOLED TRANSFORMER.

to those with straight cores, as the term ring transformers covers the other case.

Disk-Wound Transformers.—Sometimes the coils are in a number of sections wound separately into disks and piled one on top of another in alternation, as shown in Figs. 283 and others. By connecting the sections in series or in different parallel connections, the primary can be made to serve for a voltage of vary-

ing amount, and the secondary can be connected to give different potentials. A series connection of the sections is used for the high voltages, and parallel connection for the low voltages.

Pancake Coils.—Coils such as those shown in process of construction and completed in Figs. 286 and 287 are called pancake coils. They are insulated, taped, and shellacked so as to be quite strong. Such coils are often wound of copper ribbon as wide as a coil is high. The coils illustrated are used in shell-type transformers cooled by air blast.

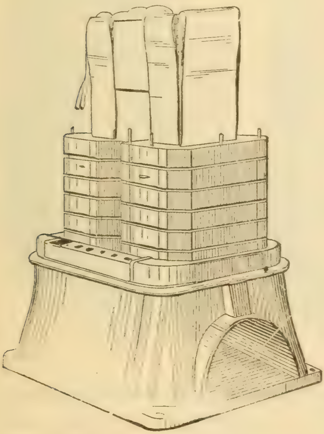


FIG. 283.—CONSTRUCTION OF A CORE TRANSFORMER.

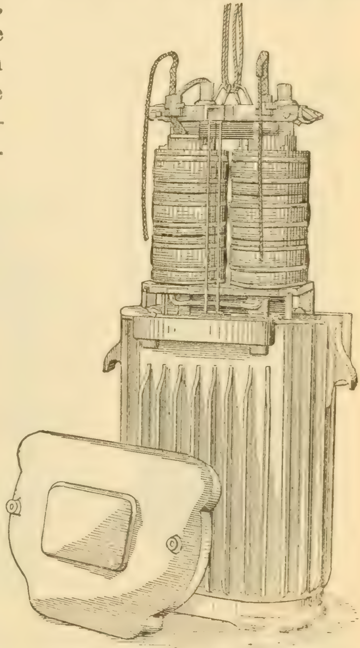


FIG. 284.—CORE TYPE OIL-COOLED TRANSFORMER.

The Auto-Transformer consists of an iron core wound with a single coil which virtually constitutes the primary and secondary. The secondary circuit is taken from it at two points; one connection is made at one end of the coil, the other at an intermediate point. The portion of the coil comprised between these points may be of wire of extra thickness. It represents the secondary coil. The voltages will be to each other as the total turns in

the coil to those in the secondary portion of the winding. It may be a step-down or step-up transformer. In the latter case the short section of coil is connected as the primary.

A similar connection is sometimes made to the secondary coil in the three-wire system as applied to the working circuits, which are the secondary circuits, of alternating current systems of dis-

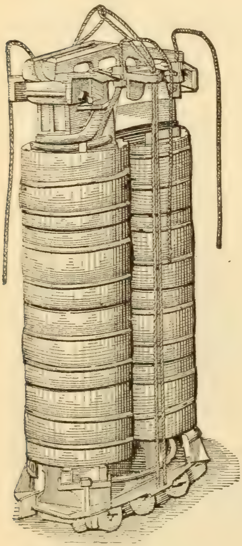


FIG. 285.—COILS AND CORE OF CORE TYPE OIL-COOLED TRANSFORMER.

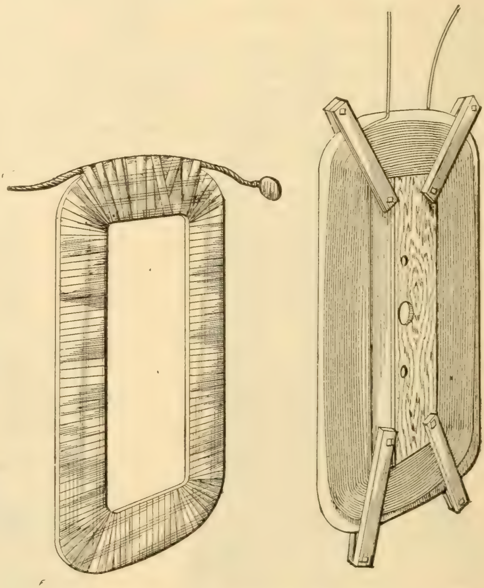


FIG. 286.—MANUFACTURE OF PANCAKE COILS.

tribution. Three wires are connected to the secondary, one in the center and one at each end. If a voltage of 220 is given by the secondary, then 110 volts will be formed between each end lead and middle lead. The centrally-connected wire is the neutral wire. This arrangement supplies current on the two-wire system until points are reached where it is to be used. At these points the transformers perform a double function, changing voltage and instituting a three-wire distribution.

Action of the Transformer.—When the secondary circuit of a transformer is open, the inductance acts to keep back the current in the primary, and the transformer becomes virtually what is called a choke coil. Some electric energy is wasted upon it, as it is not absolutely without current and the full voltage must be expended. When the secondary circuit is closed, a change of current intensity in the primary sends a current through the secondary, but in the opposite sense. Inductance is due to the energy required to increase the intensity of a field of force. The

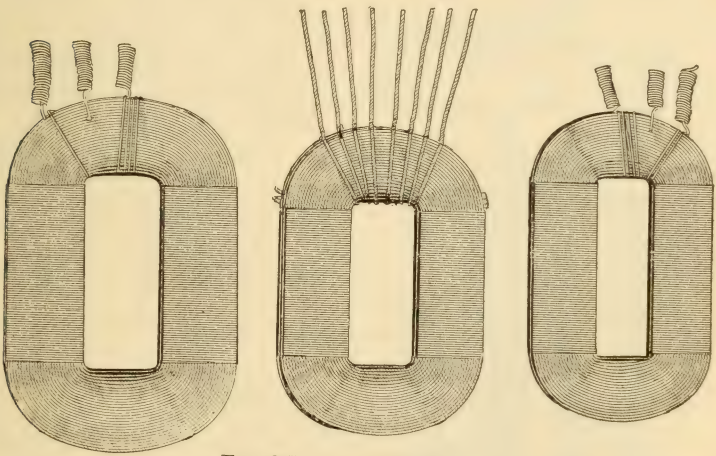


FIG 287.—PANCAKE COILS.

primary sends a current of changing intensity in one direction, which produces lines of force through the core of the transformer when left to itself, and as it expends energy on doing so is choked back. But if the secondary circuit is closed, a current in the reverse direction goes through it, and demagnetizing to greater or less extent the core of the transformer, facilitates to that extent the passage of a current through the primary.

A closed secondary circuit causes current to go through the primary; with an open secondary only a very small current can pass through the primary.

Transformers must have as good permeance as possible, and

hysteresis being a source of loss of energy must be avoided by the selection of an iron with low hysteretic coefficient, and by the use of laminated cores.

Heat in Transformers.—Transformers become heated when in use, partly from the eddy currents in the masses of metal of which they are constructed, partly from the current in their coils. Cooling of some sort has to be adopted. For small coils this is effected by the circulation of air about them and by the natural radiation of heat.

Outdoor transformers are generally of the smaller sizes, and frequently the above agencies are depended on to cool them. The radiating surface of any solid varies with the square of its lineal dimensions, while its cubic contents varies with the cube of the same. The cubic contents increases with linear size more rapidly than does the surface. Therefore, the smaller a body is, the more favorable is the ratio of its radiating surface to its cubic contents. The heat present in it from any cause varies with the cubic contents. Its output is proportional to the same, and the heat imparted to it varies with the output.

A small transformer will cool more quickly than a large one, all other elements being equal.

The tendency of electric engineering practice is to use special means for cooling transformers.

Oil Cooling.—Small converters are frequently oil-cooled. The converter is placed in a liquid-tight case, which is filled with oil. As the coil rises in temperature the oil becomes heated, and by circulating conveys the heat to the outside case. The air cools this, and thereby cooling the oil keeps down the temperature of the coil. The cut, Fig. 284, page 381, shows an oil-cooled transformer with its coils lifted out of its case. This is a core-type transformer. In use the coils and cores are lowered into the case, and oil is poured in until it is full. Fig. 285, page 382, gives a separate view of the primary and secondary of the same type of transformer, with its coils surrounding the cores.

Oil in a converter case performs another function, as it improves the insulation.

A thermometer as shown in Fig. 288 is sometimes set into an oil-cooled transformer, in order to show how hot it is getting.

As the size increases, the heat imparted rises with the cube of the linear dimensions, and the superficial area rises only as the square. The cooling power is pretty closely proportional to the superficial area. Notwithstanding the wasteful heating of transformers, large-sized ones are exceedingly economical, often giving over 98 per cent of return, a waste of less than 2 per cent.

There would be no difficulty in making the transformer so large in proportion to its output that special cooling would not be required. But this would be so expensive that it would cost more than would the use of smaller artificially-cooled transformers.

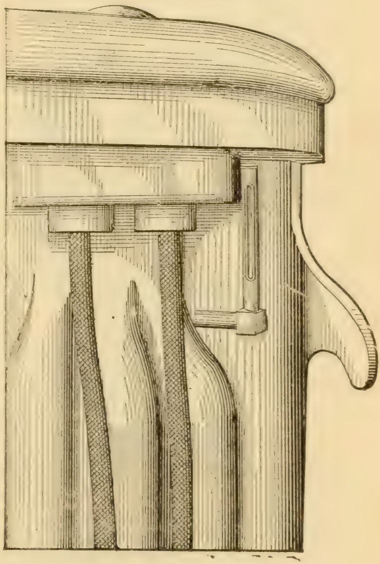


FIG. 288.—THERMOMETER IN TRANSFORMER.

A characteristic feature of many transformers is the corrugated case. The shape is given to increase the area with which the air comes in contact.

Water Cooling.—Water cannot be directly applied for cooling transformers, on account of its effect on the insulation. It is applied indirectly by using a coil through which water circulates to cool the oil. The cut, Fig. 289, shows the interior parts of a shell-type transformer lifted out of the case. The core and coils are surmounted by a coil of pipe. In use the whole apparatus, core, coil, and water pipe, is immersed in oil in the transformer case. In the operation of the transformer, as the oil gets hot, the hotter oil rises to the surface. Here the hot oil would naturally accumulate. The coil of pipe is immersed in this portion of the oil, and occupies the most effective place for cooling the oil. Water is kept circulating through it.

Air-Blast Cooling.—The cooling power of an air blast is often used for transformers. A current of air in rapid motion possesses far greater cooling power than when it is left to its natural circulation. The cut, Fig. 289*a*, shows an air-blast cooled transformer. The air enters from below through a pipe communicat-

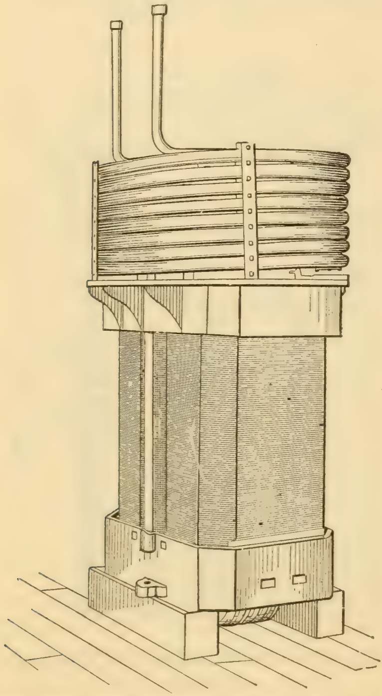


FIG. 289.—WATER-COOLED OIL-FILLED TRANSFORMER COILS AND CORE.

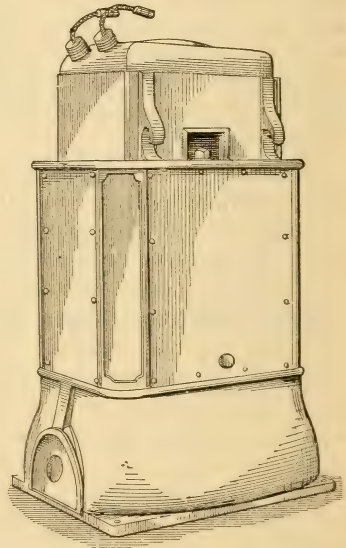


FIG. 289*a*.—AIR-BLAST TRANSFORMER.

ing with a fan or other source of air blast. The primary and secondary are wound in flat coils separated from each other by diaphragms. The core is so built up as to leave air ducts regularly spaced throughout. On the top there is a central damper to regulate the draft of air between the coils, and the damper on the side near the top regulates the draft through the core. At the

bottom semicircular doors give access to the secondary terminal. The primary terminals enter on the top.

The power required to operate the fan-blower is exceedingly small, about one-tenth of one per cent of the output. The fan is driven by an electric motor.

Disk Winding.—Constructors of transformers often wind the low-tension coils disk fashion or concentrically, with one set of turns per layer, while its high-tension coils are wound out of wire of rectangular cross section. In the large transformers a number of wires are connected in parallel. This subdivision prevents in a great degree eddy currents in the conductors, just as lamination prevents it in the cores.

The system used in the high-tension windings brings about another result. As one set of turns only is used for the width of each flat or disk coil, the electromotive force between neighboring turns is never more than 25 volts, and sometimes is only 10 volts. The principle is the familiar one used in the high-tension winding of induction coils. It is called disk winding when applied to this class of apparatus.

Ducts are arranged all through these coils, so that the oil with which they are charged starts into vigorous circulation at once when the heating due to service begins and no part of the iron is more than an inch distant from oil in motion.

In larger sizes of transformers the cast-iron covers may simply be put in place without bolting down. A case could hardly arise in which a large transformer would be placed on its side. With small transformers, their covers are bolted on, so that they can be subjected to considerable jolting and inclined positions without disturbance.

Constant-Current Transformers.—A constant-current transformer is one in which there is not a constant ratio of electromotive forces between the terminals of the primary and secondary coils, but in which a constant current is maintained by the secondary as long as a constant electromotive force is maintained at the terminals of the primary coil. This represents the requirements of series lighting.

An ordinary transformer gives on the secondary an almost constant virtual voltage and varying intensity of current. If

the coils of the transformer be so constructed that the inductance of the primary and of the secondary portions are high compared with the mutual induction between them, the coil will give a constant virtual intensity of current to its secondary. One way of effecting this result is to have a choke coil in series with the primary coil. Special constructions of coils may be constructed to answer the same end. A long core with the coils on the ends is one design.

Electrical constructors have also devised transformers in which the result described above is produced by changing the distance between the coils.

The diagram, Fig. 290, illustrates the principle. C represents

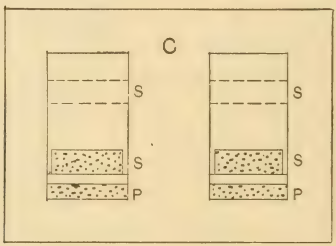


FIG. 290.—ACTION OF CONSTANT CURRENT TRANSFORMER.

the iron core, P, P, the primary, and S, S, the secondary coil. The secondary coil is movable and suspended at the end of a lever with counterpoise, so that a little force will move the secondary coil up and down.

By Lenz's law (page 213), the induction of a current in the secondary coil will cause repulsion between the coils to be exerted. This varies in degree with the current induced. Therefore, in the apparatus any tendency to an increase of current in the secondary repels it from the primary, thereby diminishing the induced current. If the current grows less, the repulsion diminishes and the coils come nearer together, and the induction is increased.

The next cut, Fig. 291, shows the construction. In this the

fixed coil is seen at the bottom. The movable coil is suspended as shown above the fixed coil. It is held in equipoise by a lever, with counterweights. When a small current is taken from the secondary, the movable coil drops, and may even rest upon the fixed one. But as more current is taken from the fixed coil, the repulsion drives them apart, so as to diminish the induced current. In this way a constant current is maintained with changing resistance on the outer circuit. The cut shows the sectional view of the transformer in the upper portion of it, with the plan below. If the resistance of the outer circuit supplied by the secondary coil is reduced by the operation of arc lamps or by cutting one of them out of the line, the current increases momentarily, the repulsion drives the coils apart, the induced electromotive force falls in value, and the current through the new and less resistance under less electromotive force is unchanged.

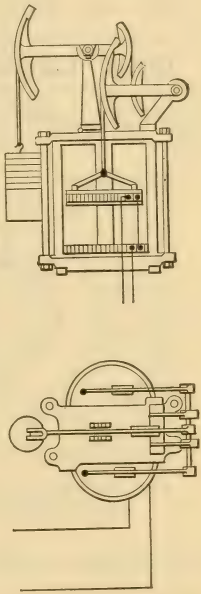


FIG. 291.—CONSTANT CURRENT TRANSFORMER.

In larger transformers of this type there are two primaries, one at the top and the other at the bottom, both fixed in place, and two secondaries poised between them. Without any output one rests against the upper, the other against the lower primary.

One characteristic feature of this apparatus is the counterpoising of one movable coil by the other one.

An auxiliary lever is provided for adjusting the effects of attraction or repulsion between the coils. By adding or removing counterpoising weights, the adjustment is made. The apparatus shown has its coils immersed in an oil tank; the oil not only acts as a cooling agent, but damps the movements of the coils.

Oil for Transformers.—The oil for filling transformers should be of low viscosity, so as to rapidly penetrate any interstice. High flashing point and high insulating value are also requisite.

Sometimes sparking will make a little tube of carbonaceous matter through oil which will constitute a permanent source of trouble.

Insulation in Transformers.—The most elaborate care has to be taken in insulating the windings of transformers. Tape, shellac, and mica are used. The laminations of the core or core plates are insulated from each other also in order to prevent Foucault currents.

Direct Current from Alternating Current.—By special connections to collecting rings on the shaft, an alternating current can be taken from an armature wound for direct current. The illustration, Fig. 292, shows a diagram of a Gramme ring wound for direct current. If rotated in a bipolar field with the connections shown in the cut, an alternating electromotive force will be impressed upon the circuit, if closed through the brushes and collecting rings. For the Gramme ring the general rule is that for single-phase current the connections must be taken from its windings at angular distances equal to the pole spaces. For four poles there should be four connections, for six poles six, all evenly spaced, and connected alternately to one or the other collecting ring.

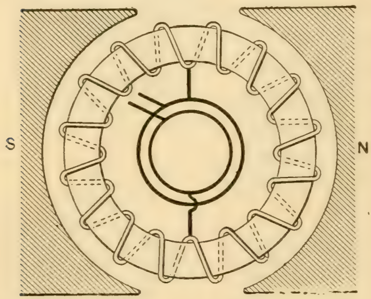


FIG. 292.—GRAMME RING GIVING ALTERNATING CURRENT.

In these windings, whether alternating currents are taken from them by means of connections to collecting rings, or whether direct currents are taken from them by a commutator, the coils are subjected to precisely the same inductive influences, and identical electromotive forces are impressed upon the windings in both cases.

Rotary Converter.—If an armature of a dynamo is provided with two sets of connections, one to a commutator for direct current and another to two, three, or four collecting rings for alternating current, a machine results which can receive one kind of

current and act as a motor and deliver the other kind of current acting as a dynamo. Such a machine is called a rotary converter. The term continuous alternating transformer is applied to it in England.

The machines can be driven by an alternating current as a synchronous motor, either for driving machinery or for generating direct current, or for both. The latter current can be taken from the brushes bearing on the commutator.

Use of the Rotary Transformer.—It is settled that for long-distance transmission of power the alternating current is to be preferred. It is in connection with such transmissions that the rotary converter is principally used. For many purposes direct

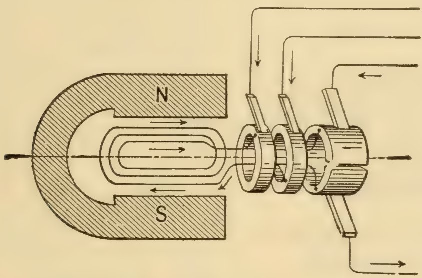


FIG. 293.—THEORY OF ROTARY CONVERTER.

current is preferable. Especially in high-voltage transmission is the rotary converter useful.

Thus, a power station may generate electric energy, and transmit it any desired distance at a high voltage, so as to need only a small transmission line. It will in such cases practically always be of the alternating-current type. When it reaches a center of distribution, the current may go through step-down transformers, thereby giving an increase of current and diminution of voltage. The current from the secondaries of the step-down transformers may be used to drive rotary converters, so as to produce direct current. Such an arrangement may be cited as particularly available for electric railroads on which direct-current motors are employed.

Principles of Construction.—The diagram, Fig. 293, shows the principle of construction. An armature is indicated by its windings, and is supposed to rotate in a magnetic field. The ends of the windings are connected to collecting rings and commutator segments. In the diagram each end of the winding connects to one of the collecting rings and then to one of the two commutator segments. Four brushes are provided; one pair for the direct current bear against the commutator, the other pair for the alternating current bear against the collecting rings.

Alternating current received by the pair of brushes bearing against the collecting rings will cause the armature to turn when brought up to speed. It becomes a synchronous motor. Direct current can then be taken from the other pair of brushes, which bear against the commutator surface. In this case it operates as a converter of alternating into direct current. It may have its commutator brushes connected to a source of direct current. It then turns as a direct-current motor, and alternating current can be taken from the collecting-ring brushes. This latter use is comparatively rare in engineering. The arrows in the diagram indicate the current relations.

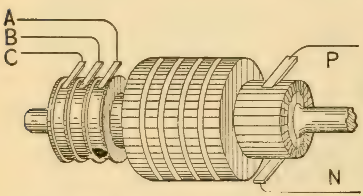


FIG. 294.—DRUM ARMATURE OF ROTARY CONVERTER.

The next cut, Fig. 294, shows a drum armature with a regular commutator at one end of its shaft, and three collecting rings at the other. From each collecting ring a wire connects with the winding of the armature. The connections are 120° apart. One result is a three-phase current if the armature is rotated in a field by a direct current. The other result is a direct current if the machine is driven as a polyphase synchronous motor by a three-phase current.

Relations of Voltage and Current.—The single-phase rotary converter operating to convert direct into alternating current impresses a maximum voltage on the alternating-current circuit equal to that of the direct-current circuit. By the law of sines

the effective voltage on the alternating circuit is 0.707 of the direct-circuit voltage. If the rotary converter is operating to convert alternating into direct current, the direct-circuit voltage will be 1.41 times the effective alternating-circuit voltage. The effective current and the direct are in great degree the inverse of the proportion indicated above. All losses are neglected in the above general statement. Analogous ratios hold for polyphase rotary converters.

The current in the armature of a rotary converter is made up of two currents. One is that which passes through it by the collecting ring brushes, the other is that which is induced by the poles, and which is delivered to the outer circuit by the armature brushes. The algebraic combination of these two constitutes the total, and as these two are generally opposite in sign, the actual current is small. This gives a small armature reaction and a small heating effect in the coils.

Whether or not it is fair to call the distortion of the field of force by armature reaction the cause of the torque, there can be no electro-magnetic torque without such reaction and consequent distortion. The nature of the distortion determines the direction of torque, concentrating the lines of force under the leading horns of the pole pieces.

The armature windings of the rotary converter, when it is performing its function of conversion of alternating into direct current, are traversed by a smaller current than when it is operated as a direct-current dynamo. The output in power of which it is capable in its different *rôles*, which is its working capacity, may be based upon the current it can carry with equal heating of the armature windings. The following power ratings are for a rotary converter used in the functions described:

Continuous-Current Generator.	Single-Phase Converter.	Three-Phase Converter.	Six-Phase Converter.
1.00	0.85	1.34	1.96

Rotary Converter in the Three-Wire System.—The Edison three-wire system can be supplied by a rotary converter on the following system, applicable for a three-phase original current. The three secondaries of the step-down transformer on the high-

tension circuit are Y-connected (page 359). The free ends of the coils are connected to the three collecting rings of the rotary converter. The electromotive force between the junction of the coils, which is the natural point of the Y connection, and either of the armature brushes on the direct-current commutator is constant and equal to one-half of the electromotive force between the brushes. The neutral wire of the three-wire system may be connected to the neutral point of the Y, the other two wires to the direct-current brushes.

Starting a Rotary Converter.—If receiving power on the alternating side, the rotary converter has to be brought into synchronism. This can be very simply done by a small direct-current dynamo, which connected to the direct-current brushes will effect the result, when the alternating current can be substituted by way of the collector ring brushes.

Functions of a Rotary Converter.—This machine can convert alternating current into direct current or the reverse. It can be used as a motor on either direct current or alternating current. It can be driven by power, and deliver either direct or alternating power or both at once. It may receive one kind of current and act as a motor, and generate the other kind of current simultaneously.

The Rectifier.—The alternating current rectifier is an appliance for converting an alternating current into a pulsating current of uniform direction, giving a series of half waves of identical direction. Its use is principally for field excitation of alternators. One or more of the armature coils is disconnected from the rest, and its ends are connected to the rectifier. The latter by its brushes delivers direct pulsating current to the field windings, providing field excitation.

The rectifier is a modification of commutator and collecting rings. It consists of a drum whose construction resembles that of a commutator. One bar or division is provided for each magnet pole, giving an even number of bars. The bars are electrically connected in two sets, so that if they were numbered consecutively, the odd-numbered bars would be connected together, and the even ones also. Each set is insulated from the other set, and both from the shaft. The rectifier is mounted on the commuta-

tor shaft of the alternator. Each set of bars is connected to a terminal of the coil. There are two brushes, which are so adjusted that one will be in contact with an even-numbered bar when the other is in contact with an odd-numbered bar; and if the two brushes are connected, then the alternating current from the armature follows this path. It goes to one brush, by a bar of one commutator set, passes through the wire of the outer circuit, including the magnet coil of the machine generally connecting the brushes, thence through the other brush and other set of commutator bars to the original coil.

The entire current from an alternator may be passed through a rectifier. The alternating current from the armature of the machine is rectified, passes from one brush through its circuit, including, it may be, lamps, field magnet of the alternator, and other things, and returns to the other brush of the rectifier. From the other end of the rectifier the original alternating current circulates through the armature.

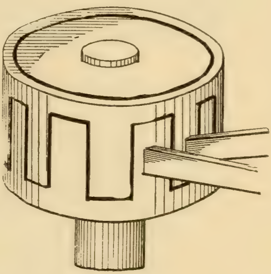


Fig. 295.—Rectifier Commutator.

A rectified current may be used for direct-current operations, such as charging storage batteries, supplying direct current lamps, etc. It is not perfectly satisfactory for some uses, on account of its pulsatory character.

A simple rectifying commutator is shown in the cut, Fig. 295. Two cylinders cut like crown gear wheels are nested together as shown, and are insulated from each other and rotate with the main shaft of the alternator. The heavy black lines indicate insulation. One is connected to one end of a wire from the armature coils; the other to the other end of the same wire. This wire may be an independent parallel winding, for the purpose of giving current to excite the field. The brushes bear one on one tooth, the other on the next tooth of the commutator. Wires from the brushes go to the field, if it is to be excited, and connect in circuit with it. As the current in the wire from the armature changes in direction, the rotation of the commutator brings the

brushes to the other teeth. The effect is to send the rectified current through the outer circuit.

An ordinary commutator can be used with its bars electrically connected into two sets of alternate bars, each set insulated from the other, provided it has one bar for each field-magnet pole.

Operation of Transformers.—It has been impossible within the limits of the space at our disposal to go into full details of the theory of transformers. Owing to hysteresis and other factors the actual operation of a transformer is not so simple as the discussion of it given here might make it appear. But the full treatment of the subject involves the application of the higher mathematics and is very intricate. The theory of the action is only given in outline and the statements are subject to qualification if the field of full investigation is entered on.

CHAPTER XXIII.

MANAGEMENT OF MOTORS AND DYNAMOS.

Starting Motors.—The current must be given to a motor with some degree of slowness, or the armature may become overheated. After the motor is in rapid motion, the counter electromotive force protects the armature to an extent more or less considerable. A stationary armature will be burnt out under conditions of voltage and current of the outer circuit, when it would be perfectly safe if in its full rotation.

The Starting Boxes.—Protection is given in their starting by the use of resistance. The resistance used is generally contained in a case with switch handle on its top and contact points. By swinging the handle from point to point, resistances are cut out one by one until none are in circuit, and the motor receives as full voltage as is possible. The motor is started with all the resistances in circuit, and in series with the armature, and they are cut out as described until the motor is in full motion. Resistances cannot be economically used for running the motor.

A simple construction is shown in Fig. 296. The switch is an arc of a circle shown in the middle of the cut. When turned clear to the right, the arc is out of contact with any of the four tongues. On turning it from the open circuit position, it first makes contact with contact No. 4, which is connected to the line. This contact is without effect. It next makes contact with No. 3. This sends the full current through the field. The next contact is No. 2. This sends current through the starting coil and armature, and the latter begins to rotate under the influence of the reduced current. Another contact remains, No. 1, which when made short-circuits the starting coil, and the armature receives the full working current. The long arc keeps all the contacts closed when in the last-described running position.

Magnetic Release Starting Box.—A series of resistance coils are connected to a set of contact studs. An arm is arranged to swing on a pivot. In its motion its outer end moves over the row of studs, making contact with them one by one. Each stud represents a resistance held in a frame, which is back of the face of the apparatus. When the handle is swung to the left, as shown in Fig. 297, all the resistances are in series with each other. As the switch is moved to the right, it cuts out the resistances one by one until none is left in circuit. On the switch handle there is an armature of soft iron, which when the resistance is all cut out is brought by the motion of the switch arm directly in front of and against the poles of an electro-magnet. This magnet is secured to the face of the box, and is connected so as to receive part or all of the current received by the motor.

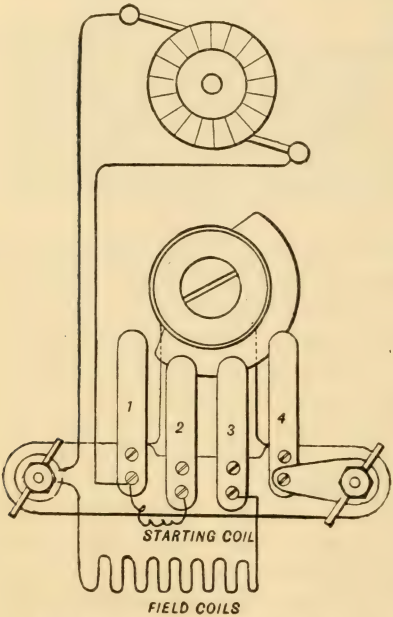


FIG. 296.—SIMPLE STARTING BOX.

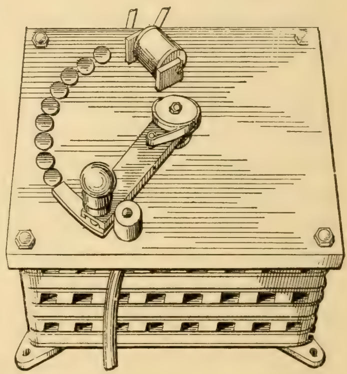


FIG. 297.—MOTOR STARTING BOX WITH MAGNETIC RELEASE.

A spring is arranged to pull the switch arm away from the magnet and across the face of the box to the position where the

current is entirely cut out, where it strikes a stud and has its motion arrested. The attraction of the magnet for the armature is great enough to hold it against the pull of the spring. If the voltage of the circuit should increase, and thus produce an overload, automatic cut-outs or fuses would presumably open the circuit. The current would cease to excite the magnet, and the armature would no longer be attracted by it; the handle would fly off to the other end of its arc and come to rest with the motor circuit open. When the circuit breaker was replaced, new fuses put in, or in general terms when current was again turned on, the motor would be cut off and would only start by the regular process of moving the starting-box arm across the resistance contacts to the no-resistance running point. If the starting box

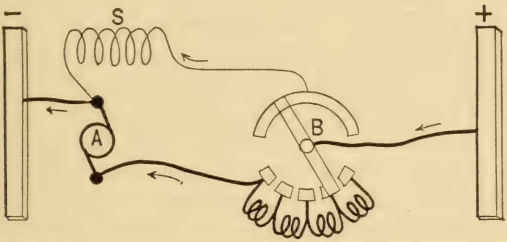


FIG. 298.—DIAGRAM OF STARTING-BOX CONNECTIONS.

is not provided with the feature described, the current when turned on again would be apt to burn out the motor armature, unless some one had had the thoughtfulness to turn off the switch arm. Various constructions and arrangements are possible to carry out this principle.

Starting-Box Connection.—The starting box is placed in series with the armature. The field if shunt-wound receives the full current which it is capable of passing; if compound-wound, the shunt winding receives its full current, the series winding receives the current diminished by the starting-box resistances. These act upon the entire armature current, but only on part of the field current in compound-wound machines. In Fig. 298 B is the starting box, S is the shunt coil, and A is the armature of the

motor. The switch handle is horizontal when the motor is idle. It is turned clockwise. It connects the field first; then keeping this connected, current is passed through all the coils in series and the armature. Then the coils are cut out one by one as the handle is turned until the full current passes.

Changing Voltage.—It is often desirable to transmit electric power at one voltage and transform it before use to another voltage. For direct current this is done by a machine called a motor transformer, motor dynamo, or dynamotor.

A Motor Transformer is a combined motor and generator. It has a single field magnet or set of field magnets, and a single armature is mounted in their field. The armature has two independent windings and a commutator for each winding; each commutator has its pair of brushes. Generally, the two commutators are placed at opposite ends of the armature.

Action of the Motor Transformer.—The current from the original station passes through one of the armature windings and through the field coils. The terminals of the line are connected to one of the pairs of brushes. The machine, as far as this current and connection are concerned, is a motor, and its armature rotates. As the armature rotates, it carries the other independent winding around, and electromotive force is impressed upon it. A circuit connected to its brushes has electromotive force impressed upon it, and if closed has a current induced.

One of the independent windings is of a greater number of turns than those of the other winding. To decrease the electromotive force, the winding of the greatest number of turns is used as the motor winding, and its brushes are connected to the actuating circuit. To increase the electromotive force, the winding of fewest turns is the motor winding.

The relation of the original electromotive force to that impressed upon the second circuit by the generating coil is determined by the relation of the turns in the one winding to those in the second winding. The cross-sectional area of the wires of the two windings is inversely proportional to the voltage expended on the first coil and impressed on the first one.

Step-Down and Step-Up Transformation.—A long fine wire of many turns in the first coil and a short thick wire of few turns

in the second coil give a diminution of voltage and an increase of possible amperage. This is a step-down transformer. A short thick wire of few turns in the first coil and a long thin one of many turns in the second coil has the reverse effect, and the combination is that of a step-up transformer.

For the first coil the machine is a motor, for the second it is a dynamo. The first coil is the primary and the other the secondary. In operation the primary coil passes a current actuated by the voltage from the station. Electromotive force is impressed upon the other coil, and any current up to the current-carrying capacity of the secondary wire, multiplied by the number of leads in parallel in it, may be taken from the brushes of what may be called the secondary commutator.

Motor Transformer Practice.—Motor transformers may be distributed all through a district. The current may be generated at a distant source, by water power for instance, and sent by several thousand volts potential through a small and consequently cheap wire circuit to any desired points in the district to be supplied. Or it may be sent to a single centrally-located transforming station in the heart of the district. Here it may actuate any number of motor transformers, and independent circuits can be taken off from each. These circuits radiating through the district will supply electric power most advantageously at low voltage.

The Economy of Motor Transformers running at full load exceeds 90 per cent. They are cheaply run as regards maintenance. The commutators need attention and ultimate replacement. New brushes have to be put on when the old ones are too far gone to yield to trimming and adjustment. The great expense is the personal attendance required. A moving machine should not be left without someone to look after it. It needs attention sometimes, even if it runs for hours without being touched. When attention is needed, it is apt to be rather urgent. A little neglect may lead to extensive injury.

The expense of the labor item represented by the cost of the attendant workmen or engineers has operated to restrict the introduction of these machines. In Europe the system has been quite extensively employed.

The other items of expense connected with it are estimated as considerably less than the interest and depreciation and energy loss charges in the direct-current low-potential distribution from a distance. Where it is possible to concentrate the transforming under one roof in the heart of a district, the conditions are most favorable for its employment.

Parallel Coupling of Dynamos.—Dynamos have to be coupled in parallel when the current to be sent out from a station exceeds the capacity of one dynamo. When the current approaches the capacity of a single generator, if it seems probable that more current is to be required, a second dynamo must be connected in parallel with the other. It is necessary also when the dynamo is to be replaced by another without interrupting the current.

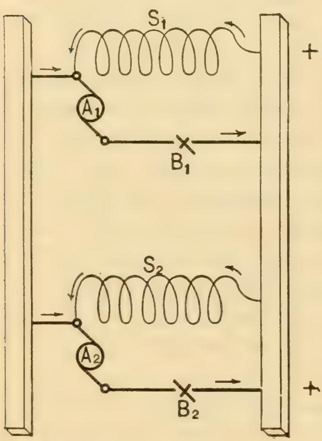


Fig. 299.—Shunt Dynamos in Parallels.

Parallel Coupling of Shunt Dynamos is shown in diagram in Fig. 299, in which the dynamos connected from bus-bar to bus-bar have their armatures indicated by A_1 A_2, the shunt coils by S_1 S_2, and the switches in the leads to the bus-bars by B_1 B_2. To throw a dynamo in, it is brought up by use of the field rheostat to a voltage two or three volts over that of the system, its main switch B being open. When the voltage is attained, the main switch is closed. A voltmeter not shown in the cut is connected to the armature brushes or to the conductors near thereto.

Parallel Coupling of Compound Dynamos.—The general connections are shown in the diagram, Fig. 300. A_1 A_2 are the armatures, S_1 S_2 the shunt coils, F_1 F_2 the series coils, B, C, and D are the switches. P Q is the equalizer. They are supposed to be provided also with voltmeters, ammeters, and rheostats for their shunt coils.

The operation of starting a dynamo in parallel is thus conducted: The switch D is closed. The machine to be thrown into parallel is started and regulated by speed and field excitation until its potential is one or two volts lower than that of the machine already working. Then the switch B appertaining to the new machine, and which has hitherto been open, is closed.

To throw out of action a machine running in parallel with another, the field excitation is reduced by the rheostat on the shunt coil until the load is only a few amperes. If this does not bring down the current enough, its speed of rotation may be re-

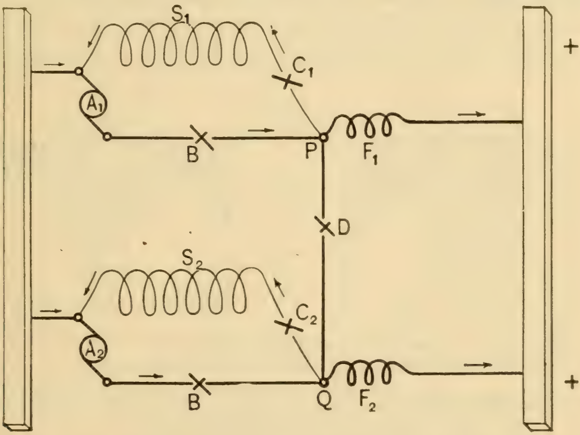


FIG. 300.—COMPOUND DYNAMO IN PARALLEL.

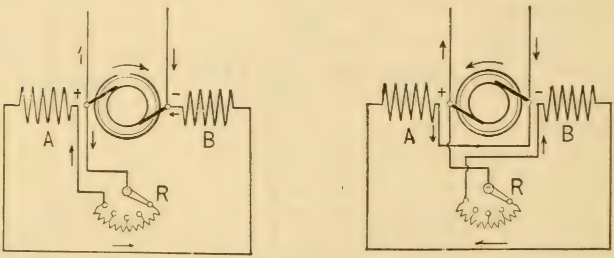
duced. Then the main switch B is opened and next the switch D on the equalizing wire.

Trouble may follow from a machine accidentally stopping, as by a belt breaking. The machine thus freed of its load may take current from the other one, and begin to work as a motor. In each machine's circuit an underload circuit breaker should be included, which will break the circuit and prevent the motor action.

Shunt-Wound Machines in Series.—These dynamos are sometimes connected in series. The only object of this connection is

to increase potential. The current capacity of the two will be limited to that of the smaller one. Thus the two may have less current output than one. The potential is equal to the sum of the potentials of the two machines.

Reversal of Direction of Armature Rotation.—The diagrams, Figs. 301 and 302, show how the connections of a dynamo must be reversed to change the direction of rotation of the armature of a series-wound machine. The diagrams represent a bipolar, shunt-wound dynamo. A and B are the field coils, and R is the regulating rheostat. The brushes are changed in position so as to give the reverse lead, and their connections are changed so as to connect them in the reverse sense with the two field coils.



FIGS. 301 AND 302.—REVERSAL OF DIRECTION OF ARMATURE ROTATION.

This throws the rheostat out, so its connections have also to be reversed. The two cuts are self-explanatory.

If the dynamo is separately excited, simply reversing the connections from the exciter will effect the requisite alteration of direction of armature rotation. This may be of special use in installations where polarity or direction of current is the critical point in operation. Such are storage-battery charging plants, electro-plating works, and direct-current arc lamp systems. In the latter the upper carbon must be the positive one. Otherwise, the greater portion of the light is radiated upward.

Polarity Tests.—Blue litmus paper moistened and held against the positive wire gives a red color. Paper dipped in potassium-iodide solution gives a black color at the same pole. Paper dipped in a solution of starch containing a little potassium iodide

dissolved in it gives a blue color. Other test apparatus and appliances are on the market.

Alternators in Step.—In running alternators in parallel, not only has the potential to be kept the same for all the machines, but the frequency of alternations or number of periods per second must be the same, and the machines must be in phase with each other. In throwing an extra machine into action in parallel with one or more running machines, all these three factors have to be kept in view. The potential is brought up to the right point by changing the excitation of the field magnets; the frequency of alternations is brought to the proper point by changing the speed.

Synchronizing.—Two transformers, T_1, T_2, Fig. 303, have their

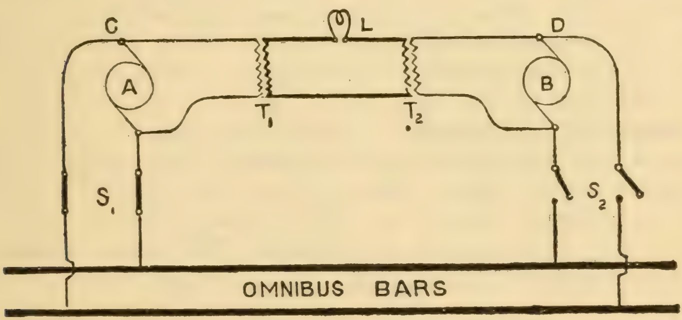


FIG. 303.—SYNCHRONIZING ALTERNATORS IN PARALLEL.

secondaries connected in series, one lead may include a voltmeter, the other an incandescent lamp, L. The primary of one of the transformers is connected to the terminals of one machine or else directly across the bus-bars; the primary of the other is connected to the terminals of the machine which is to be thrown into action. If the new machine, B, is operating in synchronism with the system or with machine A, the two transformers will co-operate in lighting the lamp. As the new machine is started, the lamps are lighted by the combined effect of the two machines. The new machine is speeded up by turning on power, and as the frequency of the machines approaches equality, the

light of the lamp begins to vary in brightness. At first the variations are very quick in following each other. As the hitherto idle dynamo is speeded up, the frequency of its phases increases and approaches closer to that of the other machine. The lamps now vary more slowly, rising and falling regularly. The rising and falling grows slower and slower until a point is reached where it ceases and the lamps burn steadily. Meanwhile the voltage must have been kept right by adjusting the excitation of dynamo B. The voltmeter, not shown in the diagram, is used to direct this. At the instant when the lamp burns steadily the switches S_2 are closed, throwing the machine into the working circuit. Its voltage must be as nearly as possible that of the circuit when the switch is closed.

The parallel working of alternators is made possible by the following fact: When running in phase with each other, alternators tend to preserve their phase relation, or to run in synchronism. If one has a tendency to change its synchronism, reaction with the other pulls it up.

Regulators or Boosters.—The potential given by a primary or secondary battery is increased by placing extra cells in series. In the secondary battery these are called end cells. If a dynamo gives insufficient voltage, an extra dynamo may be placed in series with it to add to the voltage. The second dynamo is called a regulator, compensator, and less elegantly but far more frequently, a booster.

The ways of arranging booster circuits either with or without storage battery are numerous, and are subjects of a number of patents.

Booster Connections.—A very usual method of connection is to place smaller dynamos as boosters upon the various feeders as required. The principal current is supplied by one or more dynamos running at constant voltage, which is the minimum required. From this dynamo the lines run directly to the bus-bars. From one bus-bar the feeders are led directly to the district. From the other bus-bar leads run to one set of terminals of smaller dynamos, and the other terminals of these dynamos are connected to the other leads of the feeders. The smaller dynamos are the boosters.

The cut, Fig. 304, shows a typical arrangement. The principal dynamo is shown at D, and B and B′ are the feeder dynamos or boosters. The armatures of the dynamos B and B may be in series each with its own feeder. In such case the fields are separately excited. Often current is taken from the main dynamo for this purpose. On varying this current by a rheostat, the intensity of field and consequent electromotive force given by the boosters are made to vary. The main generator has to produce the full current and more than one hundred (two-wire system) or two hundred (three-wire system) volts electromotive force; the boosters have to pass only a fraction each of the full

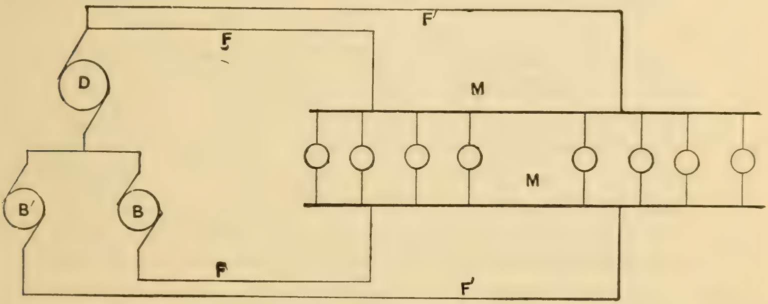


FIG. 304.—BOOSTERS.

current, and impress a few volts electromotive force on the circuit. Their armature resistance may be quite low.

Hand Regulation of Booster.—The boosters have to be regulated so as to add more or less potential to that of the system in accordance with the R I drop. The field of the boosters may be excited by independent dynamos, and the field current in the boosters can be increased or diminished by rheostats or other appliances. Thus a rheostat may be placed in series with the field of the booster, and may be used to let more or less current flow through its coils, or the exciting dynamo may be regulated by its own field rheostat so as to give more or less current to the booster's fields. The operative has to shift the rheostat handle from time to time or otherwise modify the field excitation

of the booster to suit the requirements of the supply for the district.

To carry out the hand regulating system, the armature of the booster is connected in series with the feeder line which it regulates. The feeder is connected directly to the brushes, and the armature in its separately-excited field is driven by the engine.

Automatic Regulation of Boosters.—The regulation of the potential added to the circuit by boosters can be made automatic as well as very accurate by winding their fields and armatures in series with each other and connecting them in the feeder circuit. The feeder current goes through both field and armature. As the current increases, the series-wound booster responds, because of the increased current in its field. Its field excitation grows with the current, and a higher potential is developed. As current is diminished less goes through the field-magnet windings of the boosters, and they give a lower voltage.

By modifying the field windings of the boosters, all sorts of effects can be secured, some analogous to those due to over-compounding. The feeders in the district connect with mains, and these with leads. As current increases, the drop on the feeders is not all that is decreased. The mains and leads also feel the loss in potential. The boosters can be so proportioned as to give some volts more than those of the drop on their respective feeders, so as to take care of the mains and leads also. If the drops on the feeder at maximum load were three volts, there might be one or two volts additional drop beyond the point of attachment of the feeder among the leads of the system. It is often advisable to give more potential increase within the feeder than its own drop, to compensate for the drop beyond it. It is a sort of over-compensating. This may apply to any feeder system.

Booster Construction.—The booster to act as described needs a high range of adaptability and power of varying its field strength. It may be said to require flexibility of action. The main point is to give it large field cores, so that the iron of the cores will never approach saturation, or else to have fewer turns than usual in the field coil.

Motor Dynamos as Boosters.—The current from a dynamo

may be used to actuate a motor dynamo, and the current from the generating coils of the latter may be used as a booster current. The motor dynamo is practically a dynamo driven by an electric motor. The current from the station dynamo would pass through the motor to the feeders and mains of the system. The subsidiary dynamo driven by the motor would be connected to the feeders. As the line drew upon the station dynamo for more current, the motor would turn faster, because more current would go through its coils. This would cause the subsidiary dynamo to rotate faster and to impress more electromotive force upon the system. This system would contain the automatic regulating feature.

Nowhere in the field of electric engineering does the inter-

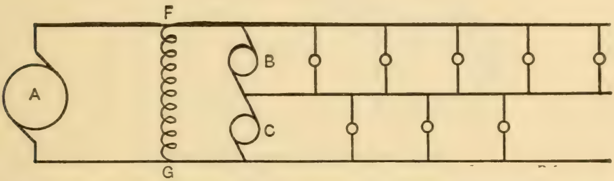


FIG. 305.—EQUALIZING DYNAMOS IN THREE-WIRE SYSTEM.

changeability of dynamo and motor appear more clearly than in the uses of dynamos now being described. Their application to regulating lighting circuits is comparable to that of storage batteries, such application being based on the double rôle which such machines can play, at one time taking power from the system and acting as motors, at another time giving power to the system and acting as dynamos.

Compensators.—This word has been used as a synonym for boosters. When a purely compensating action, and not a distinctively intensifying action, is performed, it is specially appropriate. The diagram, Fig. 305, shows the use of compensators on a three-wire system. The compensators B C are shunt-wound dynamos, coupled together mechanically, so that they rotate at the same speed. They are connected across the system, each dynamo being between the neutral and an outside wire.

In parallel with them, and between them and the main dynamo A, a resistance F G is placed across the outside leads. The neutral wire does not extend back of the compensators; it runs from between them out to the system of distribution; there are only two leads from the main generating system.

The resistance is so arranged that but a slight current flows through the dynamos when the two leads are equally loaded. If by extinguishment of lamps or other appliances the wires receive unequal current, the compensator connected to the wire carrying the lighter current acts as a motor. Turning under the influence of the current, it drives the other dynamo and generates current for the other more heavily loaded line.

Floating Battery.—Boosters are often operated in conjunction with storage batteries. A storage battery connected across

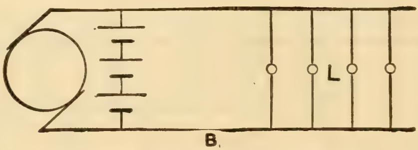


FIG. 306.—FLOATING BATTERY.

the two or three leads of a system, as shown in Fig. 306, is termed a "floating battery." It works automatically. When the voltage of the system tends to rise because of small consumption of current, the battery receives current and is charged from the main dynamos. When the district needs a heavy current, the battery discharges into the leads and assists the dynamos.

This arrangement is the simplest, and is supposed to work automatically. An auxiliary dynamo or booster is generally used to assist the regulation. It acts to raise and lower the voltage of the system.

Booster and Storage Battery Connections are shown in Figs. 307, 308, and 309. In Fig. 307 G is the station dynamo, B is a series-wound booster, S indicating its series coil; E is the storage battery and M M indicate motors in the district. At normal load the generator supplies just the right current, the voltage of the battery is equal to and opposed to that of the line,

and no current goes through the field S of the booster, and the booster voltage is zero. When the load increases and more current is taken from the station dynamo G, the voltage of the system falls a little, the battery begins to discharge through the field S of the booster, and the latter adds electromotive force to the system. If all is in proper proportion, the electromotive force added will be just enough to compensate for the drop due to the loss of potential of the main generator. The battery discharges through field and armature of the booster, and the latter

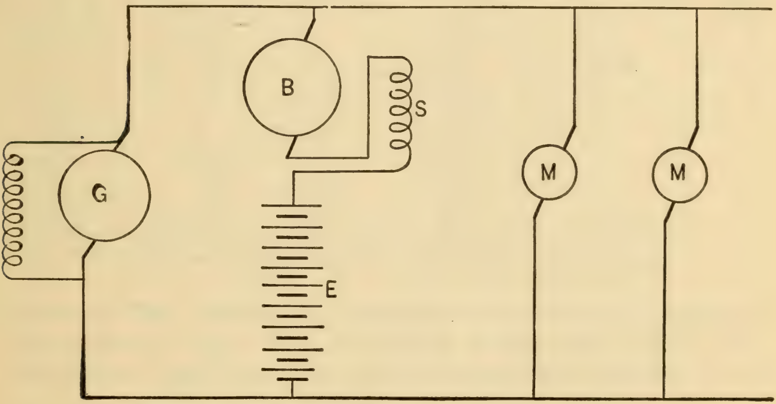


FIG. 307.—BOOSTER AND STORAGE BATTERY CONNECTION.

having its field excited with current with the polarity due to the battery's discharge, adds its voltage to that of the battery.

If the voltage in the outer circuit due to the generator rises, this holds back the battery current and the booster field becomes inactive, and the booster ceases to generate current. As the voltage in the outer circuit rises still further, it exceeds that of the storage battery, and a charging current flows. This "energizes," as it is called, the field of the booster, but with opposite polarity to the original, so that now it acts to help charge the battery.

The whole arrangement works like a floating battery. The booster reinforces the action of the battery. It may be termed a

floating booster. The system can only be used where voltage falls with load increase.

In Fig. 308 a compound-wound booster B is supposed to be

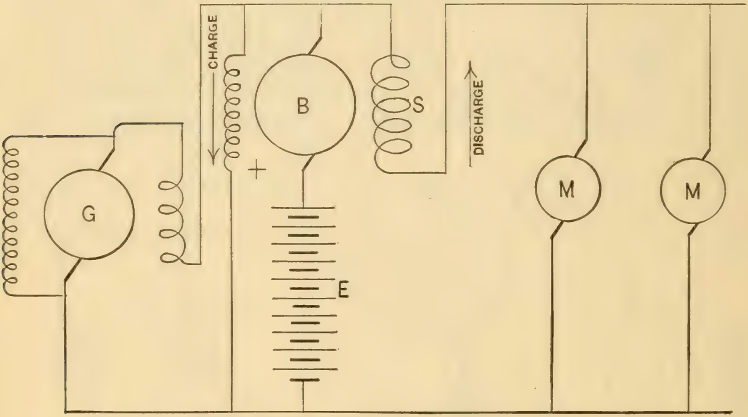


FIG. 308.—BOOSTER AND STORAGE BATTERY CONNECTION.

employed and is connected as shown. At normal load the excitation of the series field S is equal to that of the shunt field +. These two field coils are oppositely wound, so that they counter-

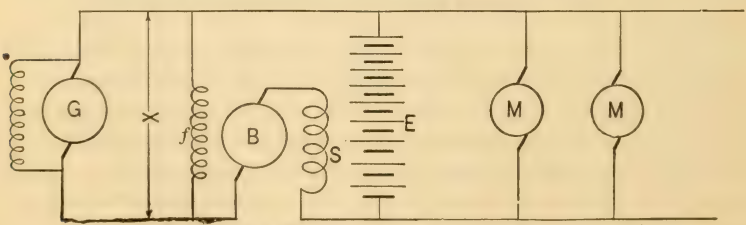


FIG. 309.—STORAGE BATTERY AND BOOSTER CONNECTION.

act each other under this condition, and the booster generates no current. If the external load is increased by more power being taken in the district, the series field coil S of the booster receives more current than the shunt coil, and the preponder-

ance excites the booster, so as to cause it to generate current in direction the same as that of the battery current. The booster and battery now add to the voltage of the line.

If the external load decreases, the series coil gets less current than the oppositely-wound shunt coil. The polarity of the field of the booster is thus the reverse of what it was. The booster sends current into the battery and charges it.

In the two last arrangements the booster and storage battery are in series with each other. The next cut, Fig. 309, shows a booster B with shunt field coil *f* and series field coil S, opposed to each other in winding, but with the storage battery in parallel with generator and motors, while the booster is on one of the leads between battery and generator. The booster voltage is added directly to the generator voltage. At normal load the magnetization of the shunt coil *f* exceeds that of the series coil S, and the electromotive force of the booster is of the same polarity as that of the generator, so that it reinforces the current due to the generator. The battery is of such number of couples that its normal voltage is equal to that of the sum of the generator and booster voltages. If an excess load comes on the system, more current flows through the line, and consequently through the series coil S. This coil works against the shunt coil *f*. Therefore the voltage of the booster is diminished, and the battery discharges on the line and takes up its share of the work. On decrease of load the field due to *f* preponderates, and the booster increases the voltage on the line until at low enough load this voltage exceeds that of the battery, and the battery receives a charge.

Crushers.—This term is sometimes applied to a motor used to reduce the potential on a feeder line. Assume that there are several feeders running out from a station, and that some require higher potential than others. The main dynamo can be run so as to give a higher electromotive force than that required by some feeders. On such feeder lines a motor would be placed which would absorb the extra voltage. The main generator's voltage would be lower than that required by other feeders, and on these feeders boosters would be placed, which in whole or in part would be driven by the motor. The latter would be a

"crusher." The term is inelegant, and something better should be found for it. The same is to be said for booster. Abbott applies the term compensator so as to include all appliances.

The Crocker-Wheeler System of Speed Control is especially designed for use in machine shops. It utilizes three dynamos, A, B, and C, Fig. 310, connected in series and with the three armatures on one shaft. The three armatures are practically connected in series across the circuit.

Suppose the circuit to have a potential difference of 240 volts. Then the three armatures are wound for 40, 120, and 80 volts respectively. Four leads are taken from the machines. One is at one end, another at the other end, and two intermediate ones are taken from between the machines. These leads are carried through the shop where power is to be utilized. The speed of the motors driven is regulated by changing the voltage absorbed by them. A two-wire power lead of definite voltage is by the rotary transformers converted into a four-wire system.

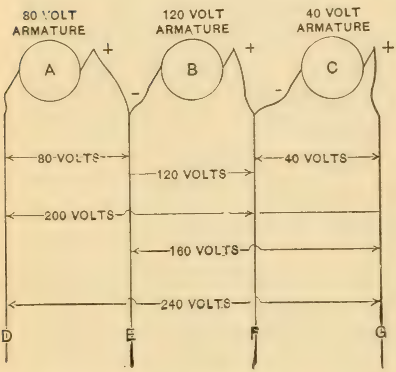


FIG. 310.—CROCKER-WHEELER MULTIPLE VOLTAGE SPEED CONTROL.

It will be noticed that the machines vary in voltage, and that the machine of highest voltage is placed between the others. The object of this will be seen. If a machine is to be run slowly, its terminals are connected across the 40-volt leads. The next degree is the 80-volt, and then the 120-volt lead. Each of these voltages can be taken off a single machine. Next the 40-volt and 120-volt machines can be put in series, giving 160 volts, then the 120 and 80 volts, giving 200 volts, and finally all three machines in series, giving 240 volts.

This gives six voltages. The tool to be driven is provided with

its own motor, controller, and resistance coil. The six voltages give six speeds. Each voltage can be modified in its action by the resistance coil. Thus twelve speeds are obtained by a single resistance coil added to the four-wire system.

Any motor can be caused to vary in speed within certain limits by the use of a rheostat, which changes the current received by it. A motor with the rheostat control superadded to the multiple voltage control can be made to vary in speed by so many degrees of change as to work almost by insensible gradations. The rheostat takes the place of the resistance coil spoken of above.

Accidents to Motors.—There are two principal causes of accidents. One is the burning out of the armature. This is guarded against by giving current slowly, by the use of a rheostat or starting box. The other is destruction of the armature windings by too high speed. A run-away motor may have the binding wires on the armature break by centrifugal force acting on the windings. The latter are then driven against the pole faces, wrecking the machine. Too high speed should be guarded against.

CHAPTER XXIV.

CARE OF DYNAMOS AND MOTORS.

Reversing the Direction of Current in a direct-current dynamo or of motion in the same type of motor is effected by reversing the armature connections. This reverses the polarity of the core, and causes it to be subject to torque in the reverse direction. If metal brushes or considerably inclined carbon brushes are used, their direction of inclination or "rake" should be reversed, to prevent the ends from catching on the commutator. Radial or even steeply-inclined carbon brushes need not be reversed. In multipolar machines the connections are shifted an angular distance equal to that intervening between the poles. The easiest way is often to simply rotate the brush yoke through the arc of this number of degrees, carrying all the brushes with it. Sometimes such reversal cannot be allowed, as it interferes with regulating apparatus. Changing the main connections reverses the polarity of both field and armature, and leaves the direction of revolution unchanged.

Stopping a Machine.—When a machine is being stopped, the brushes should be kept on the commutator until it is running rather slowly. Then they are lifted off the surface. The object is to remove any chance of injury from a possible reverse movement of the armature. Strictly radial carbon brushes are almost free from danger in this regard.

Too High Speed.—This is a cause of trouble. It may involve a strengthening of the field, so as to doubly raise the electromotive force and cause sparking, which is to be cured by weakening the field. But too weak a field is in itself a cause of sparking. A field regulator may be used to adjust the strength of field. If so, it is a good precaution to use one without any zero point, or "infinite resistance," especially in the case of

motors. A motor without load and with current passing through the armature and the field cut out, will infallibly wreck itself by racing.

Loss of Magnetic Polarity.—A field magnet may lose its polarity. This may be due to long standing, so that the residual magnetism is lost, and the machine refuses to build up. It may also be due to wrong polarization of the field by means of a current of wrong direction. Such a current may be produced when so intense a current passes through an armature with advanced brushes that the armature reaction changes the polarity of the field. This may be due, in a shunt-wound machine, to a short circuit in the field. This wrong direction of current in the magnet coils is especially to be feared in compound-wound machines. Its results are especially bad in storage-battery work. Reversal of the magnetization of a field when the machine is charging a battery converts it into a motor, and the current from the battery drives it. Thus the battery loses any charge which may have been given it. The battery as it becomes more highly charged in regular working may be the agent in reversing the polarity of the field.

Wrong Polarity of Field.—Sometimes it happens that the winding of a machine is such as to give the wrong polarity to the pole pieces of the field. This happens especially with mended machines. One thing to do is to recall the law of polarity, page 210, and to try to follow it out in the connections. Another is to try reversing the magnet connections. There should be no difficulty in arranging the connections so as to alternate north and south poles all around the field. The thing to remember is that in settling whether the current runs with or against the clock, the observer must conceive himself as facing the hollow in the pole piece which embraces the armature.

The brushes are raised from the commutator, and a current of proper direction is sent through the shunt winding for a few seconds. The machine can then be started again.

Refusal of Motor to Start.—Connect an incandescent lamp or voltmeter between one of the leads and one of the binding posts of the motor. The lamp is the best, as it operates to some extent as a current tester as well as potential tester. If the lamp

on one side shows no light, try a connection across from binding post to binding post, and then if the lamp lights, current passes, and the trouble is in the motor. If the line shows no current, a safety fuse is probably blown out or loosened. See if the brushes touch the commutator. If the line and motor seem to be all right, shift the brushes back and forth in search of the working point. If the motor will not go, it probably has too great a load. If a shunt motor is too heavily loaded, the armature refusing to start, develops no counter electromotive force, and practically short-circuits the field so as to impair the magnetization of the field.

When a motor will not start, and the connections seem to be all in order, the current should be cut off, and the clutch opened, or belt thrown off, so as to take the load off the machine. The armature must then be set in motion by hand, and the current turned on while the armature is turning. *Do not turn on the current while the hand is touching armature pulley or belt.* When the machine is rotating regularly, throw on the load gradually. Remember that a motor which refuses to start is in great danger of burning out its armature windings if the full current is left on for any appreciable time. The field coils also may suffer from overheating. This is another reason for starting slowly. Give current very slowly, and never anything like full current if the motor does not start.

Slow Speed Without Load indicates in a motor an insufficient field magnetizing current or that the connections are inverted.

Idle Motors.—When a motor is doing no work the current should be cut off. A motor running without load consumes current, and this if a meter is used, has to be paid for.

Speed Regulation of Motor Without Load.—On suddenly throwing the load off a series-wound electric motor, as by shifting a belt or loosening a clutch, its speed will be suddenly and perhaps dangerously increased. The rheostat or starting box should be manipulated so as to prevent this sudden increase of speed. A shunt-wound motor does not act thus, and does not need the above precaution.

Starting and Stopping Motors.—These operations should be performed gradually. A sudden throwing on or off of a load on

a motor affects the circuit sometimes to quite remote points. Large motors should for this reason alone be started and stopped slowly. In sudden, jerky starting there is also involved a great waste of power. Such wasteful manipulation is often very noticeable on trolley cars. The duty of the superintendent of power plants is to prevent all sudden starting and stopping of motors as far as he possibly can.

Bad Contacts Between Winding and Commutator Ears.—The wires of the armature windings in some machines, especially those of earlier date, are connected to the commutator bars by means of screws. If a screw gets loose, resistance is introduced with danger of sparking, which will occur between the brushes and the badly-connected commutator bar. Thus, on stopping the machine the defective place can be located by the appearance of the bar. Properly-soldered connections in modern machines rarely fail, unless too many wires are bunched into one soldered joint.

Temperature of Commutator.—The commutator should not rise to a temperature exceeding 185° F. (85° C.)

A usual cause of heating of the commutator is too great pressure of the brushes against its surface. Relieving this pressure by weakening the action of the springs will contribute materially to the duration of both commutator and brushes.

Collector Rings on alternators and alternating-current motors must be kept bright and clean. A little vaseline can be applied from time to time. If the surface is rough, the machine must be stopped, the brushes lifted off, the armature or rotor started turning again, and the rings may be sandpapered. Use a hollowed block of wood to hold the sandpaper.

Materials of Commutator.—To withstand the action of carbon brushes, the commutator bars are made of hard copper (unannealed). But however hard the copper may be, it is apt to be more subject to wear than is the mica insulation which lies between the bars. Too hard or unwearable mica tends to project beyond the copper after a machine has run some time, and thus impairs the commutator surface. The projecting mica tends to cause the brushes to jump up as it passes, and occasions the worst kind of sparks, with lots of "extra current" behind them. Com-

mon sandpaper is often not able to cut down the ridges. If not afraid of injury, emery or carborundum cloth or paper may be tried. The worst of this trouble is that it is slow to reveal itself.

Loose Commutator Bars.—Sometimes these are a source of trouble. By holding a somewhat wedge-shaped piece of wood on each bar and striking it with a hammer, looseness can be detected. The internal insulation of the armature or the rings holding the commutator together may be in fault. The cure is to be intrusted to a competent person only. It may differ for different cases to an indefinite extent.

Oval Commutator.—Especially if made of cast metals, commutators sometimes wear irregularly and become oval in cross section. The only cure is to turn them down in a lathe.

A Gummy or Sticky Commutator Surface will cause the brushes to chatter or execute a series of little jumps. Cleaning is the remedy, with a very little oil. Do not attempt to stop it by lubrication, as this will make resistance at the contact of brush with commutator.

Lubricating the Commutator Surface.—Sparking often follows as a result of this practice. If the surface is in good order and the brushes are properly shaped and trimmed, hardly any lubrication should be required. Electric contact of the best quality is required between the brushes and the commutator surface. Anything in the nature of grease acts as an insulator. A drop or two of oil carefully rubbed over the whole surface should be sufficient lubrication.

Brushes and Brush Holders.—These should not be so heavy that they will not readily yield to the inevitable inequalities of the commutator surface. The width should range from ¾ inch to 1¼ inch. The thickness prescribed by the manufacturer of the machine should be adhered to. For holders drawn copper is one of the best materials. Cast-metal holders are not generally recommended.

Brush Pressure.—A carbon brush may press with a weight of 2 to 2¼ pounds on the commutator; a copper brush should not press much over a pound. Good contact between carbon brushes and brush holders must be secured. For this object carbon brushes are copper-plated.

Replacing Brushes.—In putting new brushes in place, the surface resting on the commutator should be made to fit accurately. A simple way of shaping them is to hold a sheet of sandpaper, rough side out, on the surface of the commutator, and to rub the bottom of the brush back and forth thereon, the brush being held firmly in the brush holder. If the machine shows any inclination to spark with a new brush, it is well to run it without load for a while until the brush shapes itself.

Position of Brushes.—Opposite brushes should be placed so as to bear upon different portions of the commutator surface. If in the same plane at right angles to the shaft of the machine, they will wear a groove in the commutator. As far as possible, the entire surface of the commutator should be rubbed by the brushes.

Copper Brushes must be cut square at their lower end; especially is this to be done for wire gauze brushes. They should be pressed just enough and not too much against the commutator. They should not vibrate when the armature is turning. Once a week they should be washed with benzine to remove grease and oil, and should be put in service again only when perfectly dry.

Carbon Brushes are of lower conductivity than copper brushes. More carbon brushes are required for a given machine than copper brushes, which exacts a longer commutator. There must be no lost motion in brush holders or yoke. The screws and other movable parts of these portions of the machine must be watched. If anything is loosened, it must be repaired or tightened.

Setting Brushes.—In putting in the brushes, they must come in contact with the properly-spaced commutator bars. The general rule is to divide the number of commutator bars by the number of poles, and set the brushes that number of bars apart. Another way to get at their position is to lay a strip of paper around the commutator and cut it to exactly the circumference thereof. This can be divided with dividers accurately into as many equal parts as there are poles in the machine, and the divisions marked with a pencil. A simpler way is to do it by folding the paper. By placing it again around the commutator the pencil marks or the folds will show how to space the brushes. This applies especially to setting tangential metal brushes. Direct-bearing carbon brushes tend to find their own place.

If metal brushes are used, the greatest care should be exercised to avoid the commutator turning in the wrong direction, as this bends up their ends, and may injure or short-circuit the commutator bars.

The difficulty in setting brushes arises from the fact that different machines require different setting. Once set wrong, enough sparking may occur to so deteriorate the commutator that sparkless adjustment will be impossible. Another source of damage may be the simple heating of the commutator on account of wrongly-set brushes.

There is no rule to be given for setting brushes. For each type of machine it must be learned. The information can be obtained from the manufacturer if it is a new machine, or from the engineer who ran it if it is an old one.

In the old two-pole machines it was a general rule that the brushes should be 180° apart. In more recent two-pole machines the angle between the brushes is often little more than the angle subtended by one of the pole pieces. On such machines a mark is generally made for the brushes to be set by. The older machines had two marks, one for load, the other for no load. The general rule is to shift the brushes in the direction of the rotation, as a dynamo receives its load, and *vice versa* for a motor.

Hard Carbon Brushes have sometimes to be rejected. One may be what some engineers call "glass hard," often harder than glass, or may be of high resistance. Such must be rejected and replaced by good ones. They cannot be made to work satisfactorily with brushes of the proper degree of hardness.

Lifting Brushes.—When a machine is in operation generating current, a brush should never be lifted from the commutator. If there are several brushes on the same side, a single one may be lifted, but the best practice is not to do so. If there is only one brush and it is lifted, it may make an arc and burn the commutator.

A good way to test the heating of the armature is to hold the hand in the draft of air coming from it. If the armature is hot, the air will be heated.

Break in the Armature Windings.—This accident causes a motor to spark very badly and may increase its speed. On stop-

ping it, the insulation between the commutator bars between which the broken coil is connected will show the effects of the sparking. If a dynamo refuses to build up, and this trouble is suspected, the machine can be run as a motor so as to identify and locate the place by burning the insulation as just described. If there are a great many commutator bars, the two involved can be temporarily connected by solder, so as to short-circuit the defective coil. The real remedy is to connect the ends of the broken wire with silver solder. A break will sometimes only show itself when the machine is running, when it will produce flashing between the commutator and brushes. When motionless, the severed ends may spring together. By determining the exact resistance of the armature the trouble may be found, as the break will probably increase the resistance if it does not absolutely break the circuit. A short circuit may exist under like conditions.

If a commutator gets too hot, it will heat carbon brushes and get a coating from them, which will increase its superficial resistance and aggravate the trouble. The commutator blackens, and the carbon holders get hot and may become discolored. Such heating should not occur.

End Motion in an Armature Shaft is generally desirable. With the usual cylindrical commutator this motion causes the brushes to come in contact with the entire surface of the commutator if the range of motion is sufficient, and such contact favors even wearing, and the cylindrical contour of the armature is thus favored. If the armature shaft has end play, the belts are pretty sure to have irregularity enough to keep it in constant motion back and forth.

In some machines, end motion is given by mechanism for the purpose.

Short Circuits in Armature.—The windings may get their insulation rubbed off and connect with each other or with the iron core of the armature. Copper or carbon dust may be the cause of short circuits between commutator bars. A commutator brush may be in electric contact with the frame of the machine.

If a machine were perfectly insulated from the earth, such a single contact with core or frame would be without any effect.

If the frame of a machine is grounded and a ground exists in the commutator or armature, then such a contact of winding and armature core causes a short circuit, which may burn out the armature windings. When any short circuit of this character exists it is a menace, although it may do no harm for a long time. The short circuit can be sought for with a galvanometer and a source of current, such as a dry battery. The armature windings are disconnected from the field windings, and one end of the wire from the galvanometer and battery is kept in contact with the iron core of the armature or with the frame of the machine. With the other end of the wire the armature bars, brush connections, etc., are touched. A movement of the galvanometer needle indicates the contact and locates it. It is obvious that the magnet windings may be tested also by touching the exploring wire to their ends, as contact may exist between magnet core and magnet windings. Repairs have generally to be made at the factory.

Frequently a battery with wires is sufficient to detect these troubles. A spark will show when contact is broken, or the tongue may be placed between the wires, and the taste will reveal a leakage.

A single contact between the armature winding and the iron core of the armature does no harm as long as no other contact or grounds exist. Of course, it should not be tolerated, as it is a constant menace. A short circuit due to the contact of two wires of the same coil of the armature winding may have serious consequences. A dynamo with this trouble will not build up or excite itself. If the attempt is made to start it with an outside source of current, it will not absorb its full voltage, and the armature windings will begin to get hot. This will be indicated by the smell of heated insulating materials. On stopping the machine, the defective coils can be found by feeling the surface of the windings. The hottest part will be where the short circuit is. A motor will show such a short circuit by loss of power and speed. Sometimes it will not move at all. Entire or partial rewinding of the armature is the cure.

If the short circuit is between two wires of different coils, the trouble is intensified. The whole armature may be burned out if the machine is not stopped in time.

What is said of this class of short circuits applies to the armature bars. A contact between contiguous ones represents short-circuiting within the limits of a coil. If remote armature bars are connected, it represents the more serious case of short-circuiting of different coils.

Already a temporary cure for a broken coil has been described. This was the soldering together of its two commutator bars. Such soldering must never be done unless there is absolute certainty of the break. It would be better to cut the wire and bend the ends apart, to make sure of disconnection, and then to solder as described.

Sparking of the Commutator is a very serious evil. As the brush leaves a commutator bar, if all is not rightly adjusted, sparks will pass from the commutator bar to the brush. Everything in a direct-current dynamo or motor depends upon the accurate co-operation of the commutator and brushes. If sparking is allowed to go on, it deteriorates the metal parts of the commutator, and the edges of the bars cease to be straight and they lose their definition. The effect of this is to increase the sparking and with it the damage to the commutator until no remedy short of turning off the surface of the commutator in a lathe will restore the machine.

The brushes may suffer in the same process of sparking. Their trimming and shaping is comparatively easy. The commutator is the critical thing.

The sparking between a commutator and the brushes is injurious to the commutator. It is trouble enough at the best to keep a commutator in good order. To turn it down on a lathe, to trim the brushes and set them is a piece of work requiring time and trouble. The dynamo is also out of commission during this time. A commutator loses metal every time it is turned down, and if this is often necessary, it will sooner or later succumb.

The main cause of sparking is very simply presented. Followed out to its full scope, the subject may become rather intricate.

The cut, Fig. 311, represents conventionally a part of a commutator whose bars are lettered *c d e f g*. *n′ n* gives the position of the end of the neutral line. In the position shown, the arma-

ture windings indicated at W and X are sending current in the direction of the arrows. They lie in the left-hand half of the field. The coils U and Y lie in the right-hand half, and send current in the opposite direction. The currents join at the neutral point, and flow off through the brush.

It will be observed that one coil V is short-circuited and is "dead," because the brush bridges over the space between the commutator bars. As the armature turns, this coil is suddenly thrown into series with T and U and the whole of the right-hand division of the armature. Owing to self-induction, the coil V resists the passage of the current, and a spark goes across from E to the brush which has now left it. Such sparks ruin the commutator surface.

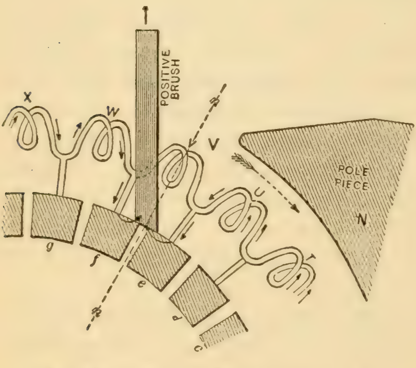


FIG. 311.—SHORT-CIRCUITING OF AN ARMATURE COIL BY A BRUSH.

But now suppose the brush advanced a little. When a coil is short-circuited, it is no longer at the neutral point, but is in say the right-hand half of the armature. It is cutting lines of force, and electromotive force is generated in it of the same polarity as that in the other coils of that half. As it leaves the brush, it is ready under the influence of that electromotive force once more to start into action and carry its current. The sparking now does not take place.

If on the other hand the brushes are swung back, then the idle coil is still in the left-hand half. It cannot be called idle any more, as it is generating an opposite electromotive force, and it intensifies the sparking action by its own supplementary sparking.

These facts must be firmly fixed in the mind. A neutral line exists in any active armature, which may or may not correspond with the position of the brushes. If the brushes are advanced

from this position, they carry the neutral line in their direction, but not as far as they themselves go. If the brushes are advanced, they therefore throw some coils into the wrong division of the armature. Such coils generate counter electromotive force and reduce the output. If the brushes are retarded, there is bad sparking; if they are advanced too far, it is less than if retarded.

The ideal would be to have the brushes in the neutral line if there were no sparking there.

If a dynamo has a weak field, the distortion of the field will be excessive. We have seen how the current induced in the coil V of Fig. 311 operates to prevent sparking. The distortion of the lines of force throws this coil into a weak portion of the field, and its action is greatly weakened. The sparking may be very hard to avoid in such case. A relatively strong field acts to prevent sparking.

The fewer the commutator divisions on a given armature, the greater will be the electromotive force represented between any two of them, and the greater will be the inductance of the windings included between them. One of the causes of sparking is disposed of by giving plenty of divisions to the commutator.

The brushes keep the coil V of Fig. 311 short-circuited while it is passing the neutral line and electromotive force is being impressed upon it. This electromotive force as already described acts to prevent sparking. It is therefore an object to keep this coil short-circuited long enough to get it working before it is thrown into series with the others. One cause of sparking is too thin a brush or a badly-trimmed one.

The idle coil must be in a strong field to be efficient in preventing sparking. The pole pieces should be so shaped as to give a strong field at the positions of the brushes just forward of the neutral line.

Short-circuiting of one of the sections of the winding may cause sparking. The mere mechanical disturbance of shaking or jumping of the brushes is a cause of sparking.

Starting a Machine.—Before starting a new machine or one which has been for some time out of service, the armature should be turned by hand to see if it is free to turn and has not got gummed bearings or too tight bearings. As it thus turns, the

windings should be observed to see if any wires rub against the pole pieces and if the axle of the armature is centered at both ends with respect to the cavity between the poles.

The oiling apparatus must be examined to see if it is in perfect condition, as lack of oil in a machine of such high-speed type may be disastrous. An iron oil can is not a good one to use, on account of the attraction the field may exert upon it. If oiling rings are used, they must be watched to see if they operate freely. In oiling, no drops of oil must be allowed to fall outside of the proper places. Especially none must touch the brush holder, windings, or commutator.

In starting, do it slowly, especially with new machines and new belting. It is well to run a machine for a while without load to ascertain if the mechanical parts are perfect and in adjustment. This will show whether the bearings are slack or the armature out of balance. If the machine has to be moved along its base to tighten the belts, its axis must be kept at right angles to the line of belting.

Starting a Dynamo.—The brushes should be lifted from the commutator, and only brought down on the commutator after the full speed is attained. The brushes must not be pressed too strongly against the commutator. If metal brushes are used, copper dust is apt to be formed, which may short-circuit the commutator bars. After a run, when the machine goes out of action, always lift the brushes.

Armature Running.—If a machine's armature is running at full speed, it should, if the power is thrown off, continue in motion for a minute or more by its own inertia.

Balancing of Armature.—An armature may be perfectly balanced for all positions when stationary, and yet not be in balance when in motion. Want of such balance causes vibration, which may shake a whole building. If a machine runs quietly, there is no need of further investigation of its rotary balance. To test it, however, the machine may be suspended in the air by its field eye-bolt and run as a motor, or less advisedly with a vertical belt. Any lack of balance will throw it into vibration. Vibration often produces sparking on the commutator.

Centering of the Armature.—The magnetic pull exercised by

the field of a machine on its armature may pull the latter out of center by springing the shaft. The pull has been known to spring the field magnet frame so that it gripped the armature and held it mechanically, arresting its motion. This point may be investigated in a new machine by passing current through the field and observing the action on the armature and field.

Armature Out of Center.—In bi-polar machines this trouble is of less account than in four-pole machines. In the latter, generally four windings in parallel with each other are on the armature. If the armature is out of center, the electromotive force impressed on the windings will be unequal. Local currents will occur to restore balance; the wires will carry varying currents; sparking will ensue, and even on open circuit the armature may become heated. It follows that too great attention cannot be given to this point.

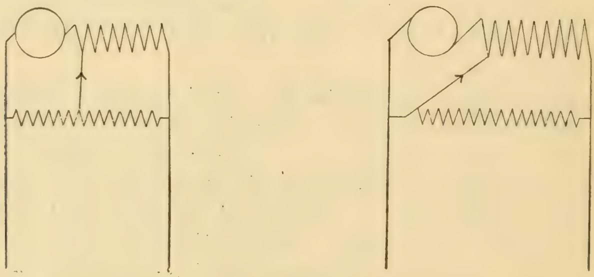
Foucault or Eddy Currents may exist in the armature core, due to insufficient lamination, too thick disks, or to bad insulation between the disks. Nothing can be done for it except to rebuild the armature. They may exist in the armature windings, due to too massive conductors. Subdivided or laminated conductors tend to minimize the trouble; sinking the conductors in slots in the core, and rounding off the edges of the pole pieces, thus altering the distribution of lines of force, also prevent it. The latter cure may introduce other troubles. Foucault currents are detected by the heat they produce. The hottest place is where they exist.

Heating of Field Coils.—In shunt-wound machines this is liable to occur from too high a current being sent through the field. Every machine is built for a definite maximum voltage at a definite maximum speed of rotation. If a machine operates with proper voltage, yet requires too high a speed for operation, or with proper speed has too low a voltage, the weakened field thus indicated will be apt to cause sparking at the commutator. But the reverse trouble of too low a speed for the given voltage or too high a voltage for the given speed indicates too strong a field. In charging storage batteries, the latter trouble may arise. Reducing the current is useless, as the field magnet current depends on the potential difference at the terminals. The voltage of

the outer circuit must be reduced. The trouble makes itself evident by heating of the field coils and pole pieces.

If one field coil is hotter than the other, look for a short circuit in the colder coil. If there is such, it will cause an excess of current to pass through the field coils, thereby heating the perfect one.

Break in the Field Winding.—This simply brings a dynamo out of action. A shunt motor may be ruined by such an accident, as its speed will, unless restrained, increase until it wrecks the armature. The trouble is easily found by a galvanometer and dry battery or by a strong current and electric lamp. If no current will go through the magnet windings, there is evidently a break. Its repair may involve rewinding of the field.



FIGS. 312 AND 313.—SHORT CIRCUITS IN DYNAMO.

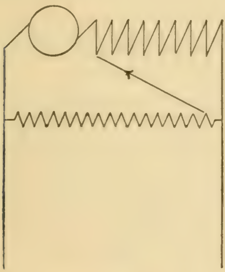
Short Circuits in Field Winding.—These are best detected by measuring the resistance of the field. They operate to weaken the field, to lower its resistance, so that it takes more current at equal potential and may give the remaining wires more load. The weakening of the field lowers the potential of the machine, and thus may often save the excessive load being given the windings. The most complicated cases of short-circuiting in the field occur in compound-wound machines. Diagrams of some such accidents are given in which dotted lines indicate short circuits.

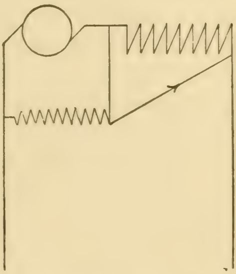
Fig. 312 shows a short circuit between the middle of the shunt winding and the beginning of the series winding. In this case one half of the shunt coil is thrown out of action, and the other

half may get heated from excess of current. Such a short circuit affects the compounding of multipolar machines more than it does that of bipolar machines. It results in over-compounding.

The next diagram, Fig. 313, shows the whole shunt winding thrown into parallel with the series winding. This is due to a short circuit between the beginning of both windings. The short circuit also operates to cut out the armature, and thus throw the machine out of action.

In Fig. 314 is shown the outer end of the shunt winding connected by a short circuit with the inner end of the series winding. If the short circuit is of low resistance, it short-circuits the series winding, and the machine has to operate as if shunt-wound.





FIGS. 314 AND 315.—SHORT CIRCUITS IN DYNAMO.

Sometimes a shunt-wound machine has the outer end of the shunt winding connected to the inner end of the series winding. In such a machine a short circuit between the outer ends of the two coils will short-circuit the series coil, and the machine acts as if shunt-wound. This condition is shown in Fig. 315. The exact condition shown in Fig. 314 is brought about.

Earthing Dynamo Frames.—The windings of a dynamo or motor must be carefully insulated from the earth. The frame, on the other hand, is to be connected thereto. It is pretty sure to have such connection in any event. Small motors may be insulated altogether. To test grounds in the windings, a wire, with an incandescent lamp in circuit, may be connected to one of the bolts of the frame of the machine, and its other end brought into contact with any exposed part of the winding. The hands

should be carefully protected, either by using thickly-insulated wire or by India-rubber gloves. If the lamp becomes hot, a ground exists. Two lamps in series can be connected across the two main leads with the wire between them connected to the earth. If the windings on both legs of the field are in contact with the core, the lamps will light feebly.

Short Circuits in Outer Circuit.—Sometimes a short circuit on the outer circuit may happen when no current is being delivered, and the generating machinery is at rest. This takes away current from the shunt field circuit, and the generators will not build up a current. Nothing can be done except to find the trouble and rectify it. It is a very disagreeable occurrence, as the short circuit may never be even suspected until the time arrives for starting the generators affected by it.

A short circuit on the outer circuit may be occasioned by neglect of customers to turn off their lamps or motors. A number of such left connected in parallel on an inactive circuit will interfere with the starting of the generator, just as if an accidental short circuit occurred between two leads. If lamps are kept burning and motors going until the current is shut off at the generating plant, they should be switched out by those in charge. Automatic cut-outs can be used for motors, which will cut them out when the current ceases.

A temperature of 72° F. (40° C.) above the atmosphere is given by some authorities as allowable for dynamos and motors in action.

Wrong Connections in Compound Dynamos.—When a compound-wound machine refuses to work, if a dynamo will not build up, and if a motor does not turn unless a short circuit such as has been just described can be detected, there is reason to suspect that the series coil of the field is wrongly connected. If inverted in connection, it will work in opposition to the shunt coil. This destroys the field excitation. Such wrong connection simply reduces a compound dynamo to inaction. But in the case of a compound motor there is danger of an accident. It is necessary to use great care in starting compound-wound motors lest such an accident should occur.

Turning Down a Commutator requires special care, as copper

is a very tough metal, and the breaks between the bars may make the tool jump a little, causing irregularity in the work. A diamond-pointed tool taking a very fine cut is recommended. The fine cut is desirable, not only to secure finish, but to avoid using up the commutator. Were there enough of such work to be done, a milling machine would be useful. After the turning, the spaces between the bars should be brushed over to remove copper dust from the mica.

Sandpapering and Smoothing a Commutator should be done when it is cold. If the mica tends to project, it will project more when the commutator is cold than when it is hot. This enables the sandpaper to better remove it. Another good point to be noted is that the increased projection of the mica causes its removal by sandpaper to be done with less expenditure of the copper of the commutator bars, which it is highly desirable to save.

To Sandpaper a Commutator, a block of wood cut to the curve of the commutator, so as to take in at least one-third of its length, may be employed with which to apply the sandpaper. Tallow must be applied to the paper or armature surface, to enable the sandpaper to cut the mica. Rarely use a file, as this is apt to wear the surface of the commutator unevenly. If a commutator has to be turned off, care must be taken lest short circuits form by copper being crowded across the intervals between the bars.

If one or more bars of the commutator show excess of wear, it indicates bad contact between the connection from the bars in question to their respective coils, or some other bad contact to be sought for in or about the coil in question.

Filing a Commutator.—This is sometimes done. A bastard-cut file is used, and the armature is slowly turned during the filing. Filings must be carefully removed from between the commutator bars; a sharp hook-shaped tool will do this. A bellows will blow away all loosc filings.

Short Circuits.—A short circuit between the primary and secondary coils of alternators, alternating current motors or transformers, is dangerous to life. It may be brought about by lightning stroke. It will destroy lamps, motors, and the like by the high potential thrown upon the line. The cases in which

this may occur are such as the following: The primary or high-tension line of a system may have a single ground connection, and the low-tension or secondary may also have one. As long as the two circuits are insulated from each other, no harm need result, although a ground on a high-tension circuit is a perpetual menace to life. If by any cause such as a stroke of lightning an arc is started across from primary to secondary, this arc will connect electrically the two circuits, will burn out lamps and motor windings, and blow out fuses on such portions of the low-tension secondary circuit as lie between the arc and ground connection.

Alternating-current dynamos are free from one source of trouble, the commutator. If short circuits are produced in their coils, the absence of a commutator involves the absence of sparking. The latter, while injurious to the commutator, has the attendant merit of being an indicator of trouble. There is no such indicator in alternators. Heating of the coil affected by the short circuit is the sign of trouble.

Modern alternating-current generators generally have a revolving field and stationary armature, sometimes called the stator. When the stationary armature is used, breaks in the windings very seldom occur, and are easily found by exploring with a source of current, and any current indicator. A dry cell and a simple galvanometer may suffice, if the machine is absolutely out of action and disconnected from every possible source of current. Such disconnection should be regarded as imperative in almost all cases where explorations have to be conducted.

Short circuits in the armature windings bring about local and dangerous heating. Such reduce also the current output of the generator, as the defective coil is no longer effective, and by its high current intensity operates to demagnetize the field. If the place where the windings are short-circuited has been found, and is accessible, a temporary repair may be made by pushing in mica between the wires. Sometimes the coil can be safely cut out and the neighboring coils can be connected across the interval. This is safe when there are enough coils on the armature. Short circuits in modern alternators can hardly occur between separate coils.

Short Circuits Between Armature Windings and Frame are dangerous not only to the generator, but to the lives of the operatives if a ground circuit is on the line. A 200-volt tension has killed in several recorded cases. A common practice is to ground the framework of alternators. Then if a man touches the frame of a machine in which such dangerous short circuit exists, he is merely in parallel with a portion of the frame and receives no injury. Were the frame not grounded, he might be killed. If no ground circuit exists on the line, such a contact of windings and frame may remain undiscovered indefinitely unless watched for. It would be well to explore inactive and disconnected machines to detect such.

Alternator Brushes.—On an alternator never lift a brush while the machine is working, except where there are several in the set. Then one may be raised at a time, some being kept always in contact. It is bad policy to work much around an alternator when it is in action.

Trouble in Rotors of Alternators may be caused by bad condition of the collecting rings, which may be dirty, unevenly worn, or oval. A periodic breaking of the circuit at the brushes due to such causes will occasion sparking. The cure is to attend to the rings and brushes and remedy their defects. The large number of poles of the usual type of alternators makes short-circuiting unlikely in them, as the copper is distributed in smaller masses, and the insulation is not so subject to wear. Another effect of this subdivision of windings is that if one winding gives out, it can often be cut out and short-circuited, and the machine kept in action until the chance occurs to replace or repair the defective coil. Cutting out a pole merely exacts a little higher magnetizing current, and no sparking results.

Self-Starting One-Phase Motor.—To make a one-phase alternating-current motor self-starting, a capacity is introduced into the main exciting circuit or an inductance into the shunt circuit. This splits the current and delivers a two-phase current to the motor, establishing a rotatory field. One of the most frequent sources of trouble is to be found in this capacity or inductance. If either of these is out of order, the current will not be properly split, and the motor will not start. A condenser with iron plates

immersed in caustic-soda solution is sometimes used as a starting capacity. By evaporation it is liable to change. The inductive coil is to be preferred to such a capacity apparatus.

Local Heating of the Windings of the Stator in an induction motor indicates a double short circuit either in a single coil or in two neighboring coils. If wound for Y distribution, an interruption of one phase will interfere with the running of the machine. If the load is light, it may go on as a synchronous motor. Sometimes the beginning and end of a coil are interchanged in their connection, so as to reduce the phase difference to 60°. This interferes with the running of a three-phase Y-connected motor.

Induction Motor Rotors.—The short-circuited disconnected rotor of induction motors seldom gives trouble. In the older type the rotor would sometimes become so hot as to melt the solder on the connections of the windings. This by opening the circuit would bring the machine to rest. For this reason it is the best practice to use no solder on the joints, but by hard metal couplings or brazing to secure heat-proof joints.

Synchronous Motors, whether single or polyphase, should be speeded up before loading, and the load should be gradually applied only after the full speed has been attained. They must not be overloaded, or they will be brought to rest. These motors have the feature of maintaining a constant speed as long as they run.

Polyphase Induction Motors, which can endure an overload within certain limits, lose in speed as the load is increased, but are self-starting even with a load.

Field Magnets of Alternators often constitute the rotating part, which exposes their windings to a certain strain and wear, from which they are exempt in direct-current machines. But their windings per pole are generally lighter than in direct current machines, which operates to save them from the action of centrifugal force and shocks and strains at starting and stopping. If sparking appears at the collecting rings and brushes, it may be due to periodical breaking of the field circuit, bad material of rings or brushes, dirt or oval rings. If the trouble is in one magnet pole, it can be short-circuited as a temporary expedient.

Two-Phase Operation.—If a two-phase station is operated by two single-phase transformers in parallel with each other, if one

breaks down the station must be run on one phase until repairs are effected or the transformer is replaced. If a three-phase station is operated by three single-phase transformers in mesh or delta connection, and one breaks down, the station can still be run three-phase with two transformers, although on full load they will be greatly overloaded.

Breakdowns in Transformers seldom occur. The principal one to be apprehended is a short circuit in the high-tension winding. This in a dry transformer will slowly carbonize the insulation, and short-circuit a more or less considerable part of the winding. With disk-wound transformers, such as those using pancake coils, this trouble is minimized. If the short circuit operates to throw many turns out of action, the potential of the low-tension coils will increase perceptibly if such are the secondary coils. This is an indication of trouble which will be seen on the voltmeter or possibly in lamps. The transformer will be caused to rise in temperature, and will pass more current when unloaded than it should under normal conditions. If it is a step-up transformer, a short circuit in the high-tension secondary will lower the potential.

Care of Transformers.—These must be kept dry. If immersed in oil, the oil will take care of them. If air-cooled transformers are to be stored in a place where moisture is to be feared, chloride of calcium may be placed on trays or saucers inside the cases. This has to be renewed as it gets moist. Quicklime is also available for the same purpose. These precautions do not apply to dry storage apartments. Dust is injurious especially to oil-cooled transformers, as it tends to thicken the oil. Dust may make short circuits.

Transformers long out of use must be started with the precautions exacted for new ones.

As long as transformers are working, they should not be touched. If anything is to be done to them, they should be disconnected. This applies especially to operations on the high-tension side, such as putting in safety fuses.

Oil for Filling Transformers is a petroleum product specially prepared for the purpose. It should have a very high flashing point; 500° F. (260° C.) is given as a proper temperature of

flash. Before pouring it into the tanks of the transformers, it should be heated to 160° F. (71° C.) It must be poured or pumped in carefully, and must be kept off the cable ends. It must rise over the tops of the coils. The insulation absorbs more or less of the oil, on which account it is advisable to inspect a newly-filled transformer from time to time, to see if it needs more oil. After three or four weeks all should be absorbed that will be taken up. Oil filling must be done under cover if there is any fear of water getting in. Every two or three years, renewal of the oil is advisable. New transformers should be inspected, to see if any foreign bodies have lodged within them. Such should be removed.

Moisture in Transformers must be watched for carefully in their first run of ten or twelve hours, as any present is expelled during this period and there is danger of its collecting into drops. If such appear, the transformer must be cut out of the circuit and dried as well as possible with a dry cloth or blotting paper. After such partial drying the heat of the core will complete the operation rapidly.

Inspection of Transformers.—Every four weeks transformers should be inspected. The high- and low-tension safety fuses should be examined. After dusting it off the cover should be removed, the contents cleaned, and the capacity of the safety fuses should be noted.

Short Circuits in Transformers.—If a transformer strikes across from high tension to low tension or to the case, supposed in this instance to be grounded, the safety fuses should melt and cut out the transformer. Short circuits in the same coil, which are generally to be apprehended in the high-tension coils, are not so easily detected. The noise of the transformer is apt to increase in such case, the oil gets hot, and the iron case is warmer than usual to the hand. The heat impairs the quality of the oil. The transformer should be disconnected and repaired. There is even a possibility of an explosion, as the heated oil may give off gas enough to be inflamed on the melting of a safety fuse.

Transformers need to be well protected from lightning.

CHAPTER XXV.

STATION NOTES.

Temperature of Dynamo or Motor.—It is not easy to accurately determine the temperature of the coils of a machine. The best that can be done with ordinary appliances is to put a thermometer as well in contact as possible with the part to be tested, and to cover the place of contact with cloths to keep in the heat. The cloth must be so disposed as to form a little chamber for the thermometer bulb. The temperature of 122° F. (50° C.) is given as the maximum allowable.

Cleaning New Machine.—A new machine should be cleaned before being set at work. Chamois is a good material to wipe it with, as it leaves no threads or lint hanging to the bolt heads, nuts, and screws of the machine. Dust can be blown out of inaccessible parts, as among the end wires back of the commutator, with a bellows. Anything in the shape of filings may go to short-circuit adjacent commutator bars.

Interchangeability of Parts is expected almost as a matter of course in buying a standard American machine. It is of the greatest convenience, and often of the greatest importance, to be able to get parts on short notice. But the moment this system acts to discourage improvements, it exercises a sterilizing effect. A first-class manufacturing company should keep in stock a full line of parts of all their principal machines, but the inevitable accumulation of parts should not discourage the course of improvement.

Cotton Waste.—Never use cotton waste in cleaning a machine, as threads from it will catch in and stick to the commutator and other surfaces.

Access of Air.—Air is so constant a cooling agent, that free access of it to motors and dynamos is highly to be recommended.

Boxing up or inclosing in closets of dynamos and motors, except for very intermittent service, is to be condemned.

Oiling.—Before starting a machine, turn the armature by hand. This will disclose any friction. This precaution should be taken for generators or motors, unless they are in such constant use that the operative is certain that their oil feed is in perfect order. Want of oil will wear the journal boxes, and throw the armature out of center. The greatest care of the oil-feeding apparatus is requisite, because this class of machinery runs at high velocity. The best and purest oil should be used, and once a satisfactory oil is found, its use should be adhered to. If the oil is fed by wicks, the drip of oil from the bearings will show that they are in order. Oil once used should be filtered or water-purified before being used a second time. Oiling rings must be watched to see if they move properly around the axle. When the old oil gets thick, new must be added after drawing off the old. Before adding the new oil it is a good plan to wash out the oil trough with kerosene oil. A small syringe is useful for this purpose.

Oil should carefully be kept off the brush holders, commutator surface and wire windings of field and armature.

Ring Oiling is much used. Rings several times the diameter of the axle hang on it. Their lower portions dip into a tank of oil. As the shaft revolves, they travel around it and feed oil to its upper surface from the tank in which they dip.

Bearings.—If new machines are started without due attention being given to their bearings, heating, burning fast, or even melting (if babbitted) of the journals is liable to occur. A good plan is to pour kerosene through the bearings until it comes out clean. This leaves them ready for lubrication, by washing out dust or dirt which may have collected. Too stiff or tight belts cause heating of the journals. These are especially to be anticipated in new installations. If belts have to be tightened, it should be done slowly and a little at a time, with periods of running between, until they are just right.

Belts too tightly stretched may even occasion melting of the bearings.

Bearings are generally so constructed that with proper management they will not heat. Insufficient oil, too thick oil which does

not penetrate, dirt and dust getting into the bearings, are causes of heating. Cleaning with kerosene followed by the application of good lubricating oil is the cure.

Safety Fuses should be inspected to see if they are tightly screwed down or clamped, and if their contact faces are clean.

Insulation of Windings.—Watch for bare spots or weak spots on the insulation of the wires of the winding. If any such appear, they must be taped or insulated in some way.

Broken Wires, even if thickly insulated, can be detected by the feeling, when the wire is slightly bent or moved. If the insulation shows signs of burning or of overheating, a fracture may be suspected there.

Soldering.—Never use acid in soldering wires together. Anti-corrosive soldering fluxes are sold, which operate on iron and copper as well as acid, and whose use is not followed by any bad after effects of corrosion.

Nails, Tacks, and Iron Filings may do harm by being attracted to a machine by its field magnets. Bronze spanners are recommended in place of iron ones. An iron object suddenly drawn to the field may, by rubbing against the armature or striking the screw heads or windings, near the commutator, do harm.

Screws in Binding Posts and connections should be looked after; imperatively so if their color indicates overheating.

Covering Machines, dynamos and motors when not running is recommended.

Emergency and Danger Signals.—A sudden rise of voltage or of current, sudden sparking at the commutator or elsewhere, heating of the windings, or smell of heated insulation should be a danger signal, and the current should be cut off from the machine showing any such manifestation. A working test of dangerous heating is the ability of the hand to stand it. If the hand can be held on the windings, they are reasonably safe from overheating. For each dynamo the allowable heating should be learned, so that by holding the hand on it, any unusual heating can be detected.

In throwing open the main switch in such a case, do it quickly to avoid arcing, and have the engine watched to prevent its racing as the load is taken off.

If a safety fuse blows out, do not put in a new one until the cause of the blowing out is known and overcome. Always use the regular fuse wire. Never substitute anything except in emergency.

Keep all switches perfectly clean as regards their contact surfaces especially.

Whenever a machine goes out of action, it should be examined and cleaned. If any oil has fallen on the coils, it should be wiped off, and oily places generally should be cleaned. Dampness is bad for machines, and dripping water may make dangerous short circuits.

Rheostats and resistances are often strongly heated in use, so no combustible substance, oily waste especially, should be allowed near them.

Forgetfulness and Negligence are justly said to be the cause of many troubles. Thus, in stopping a motor, or in case current is cut off without notification, it is absolutely necessary to bring the handle of the starting box back to the starting position, so as to throw in the full starting resistance in series with the armature, to save it from burning out when the current is again turned on.

Keep One Hand in Your Pocket is an old and a good rule to follow when working around motors and dynamos. If good new India-rubber shoes are worn, the safety is increased. When work must be done around a high-tension active machine, such precautions as wearing India-rubber shoes are eminently proper and not at all extreme.

Treatment of Electric Shock.—The first thing to be done when a man is injured by contact with an electric circuit is to get him out of contact therewith. If possible, open the circuit or stop the generator. Drag the man away from the conductor or conductors. Do not touch his hand or any part of his skin in doing this, handling his clothes only. If they are wet, throw a dry towel or other cloth over them before touching them. Otherwise, the one helping may be shocked. Especially dangerous is touching the surface of the body directly.

A physician should be called as quickly as possible. It is a grave responsibility to neglect this. Do your utmost to rescue

the man, but get professional help instantly or as soon as practicable.

If the man is in contact with one conductor and cannot be released, break the ground connection of his body. Push coats, a blanket, wooden boards, and the like under him. In doing this, stand upon a dry board or coat; if you have them, put on India-rubber gloves before handling even his clothes. When thoroughly insulated from the ground, the rescuer can try to open the man's hand if that is cramped upon the conductor. This is very dangerous unless India-rubber gloves are worn or a dry towel is used to protect the one doing it.

The two leads can be short-circuited by throwing a chain or bare wire across them. This undoes the effect of a ground. It is a rather desperate thing to do.

When the senseless man is free from the contact, remove clothing from around his neck and his waist, so that he will be free to exercise his breathing organs and muscles of the trunk and diaphragm. He is then to be treated as if he were to be resuscitated from drowning. Artificial breathing is to be started.

Place him on his back, with a pillow or other support under his neck and shoulders, *not under his head.* His head will drop back, and the top will almost touch the floor. Open his mouth and hold it open, seize the tongue between finger and thumb with a handkerchief between, and draw it slowly forward. The root of the tongue must move outward as this is done. It is useless to merely elongate the tongue itself. When satisfied that this action has taken place, let the tongue slowly go back. Repeat this double movement about fifteen times a minute.

While this is being done, a second person can assist the breathing by moving the arms up and down. He should kneel back of the man's head with face toward him, seize his arms at the forearms, press them strongly against the breast-bone, and then lift them slowly in the arc of a circle over his head, and after a short pause return them and press them against the chest again.

Let the man manipulating the tongue call "one" as he draws the tongue forward. The arms are now pressed against the chest. This represents expiration of the breath. "Two" is called, and

the tongue is slowly allowed to go back and the arms are raised as described. This represents inspiration. Again "one" is called, and the tongue is drawn out and the arms returned. Thus every four seconds the double movement is repeated, arm motion and tongue motion keeping time with each other.

It is easy to experiment with one's own tongue, and thus study the effect of manipulating it. It will be found that a drawing down over the chin as well as outward opens the windpipe.

The first sign of resuscitation is natural inspiration. See that the tongue is drawn forward, so as not to hinder the access of air to the lungs. *By no means pursue the movement of expiration until the incipient natural inspiration is completed.* Keep the arms raised and tongue drawn forward until it ceases. Then repeat the expiratory movement. Do not get excited, but do all slowly and with clocklike regularity. When he breathes regularly, he may be brought into a more upright position, and removed to a bed or other better resting place. Before this a physician should be at hand to treat him further.

CHAPTER XXVI.

SWITCHBOARDS.

Switchboards.—These are vertical partitions, generally made of marble, on one side of which are installed rheostats, bus-bars, voltmeter switches, and connections of station apparatus, and on whose other side are installed handles for operating the rheostats and voltmeter switches, automatic cut-outs, safety fuses, switches, voltmeters, and other appliances.

The general system is to make the switchboard in panels. Each panel is about two feet wide and six to eight feet high. It stands vertically, being supported by braces at its top running back to the wall of the building, thus having a space behind it, so that its back is accessible. Any desired number of panels are joined side by side.

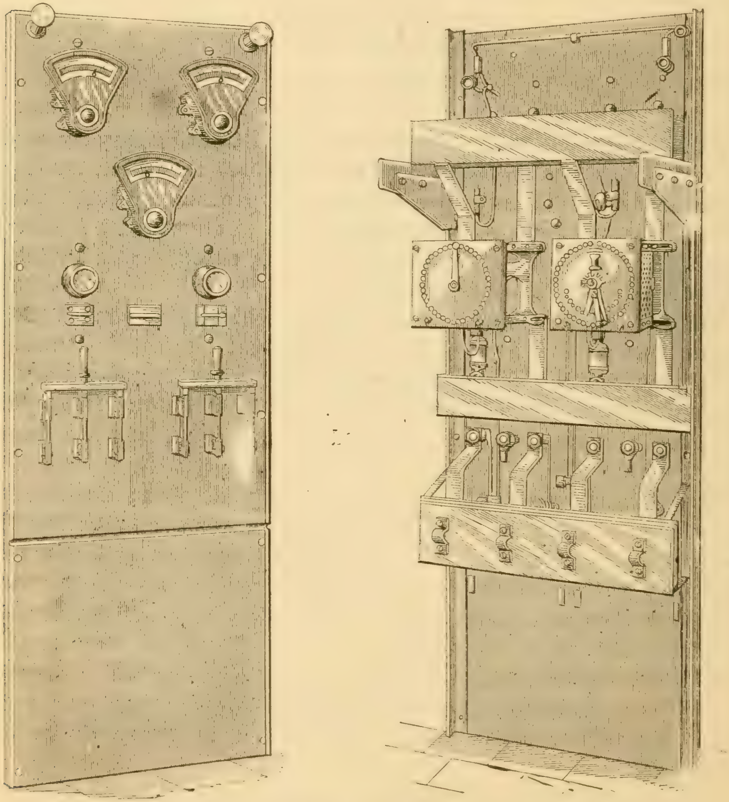
Panels.—Of panels there are various kinds. Some are for motor control, others for dynamo running, others for operating the outer circuit, others for storage-battery charging and the like. As many as are required by the station are set up side by side, so as to present a long front. The variety of panel chosen depends on the work it is to do.

The description of a switchboard is little more than a description of the apparatus which it carries. Every engineer must study the switchboards in his own station, as the varieties are numerous.

The General Electric Company manufactures a line of standard panels, which are so varied in design as to cover almost any desired case.

The front and rear views of a generator switchboard panel are given in Figs. 316 and 317. Toward the bottom are triple contact switches, which close both leads of the circuit, and also the equalizing conductor if compound dynamos in parallel are used.

On the rear the horizontal flat conductors are bus-bars. On the sides of the rear view are seen rheostats operated by handles in front. Voltmeters are placed near the top. The central connection



FIGS. 316 AND 317.—FRONT AND REAR VIEWS OF A DIRECT CURRENT SWITCHBOARD PANEL.

of the switches, intended for the equalizer, is left unconnected if the generators controlled by them are shunt-wound. Reference may here be made to page 403, showing the use of the equalizer.

Switchboard panels are named, from their uses, generator pan-

els or feeder panels, and also from the current they are arranged for, whether direct or alternating.

Air Switches.—Of these there are a large variety. The principal working contact made by closing them is a knife-edge contact, made by a thin copper bar on the switch going edgewise between two leaves of copper that spring against it. This makes one of the best kinds of connection, but in breaking it an arc is apt to form. To prevent this, switches are often provided with auxiliary contact blocks of carbon. These are so arranged as to be the first to make and last to open. An arc between carbon surfaces will not draw out as will one between metal surfaces, and if it does form, it does no harm. Metal electrodes are burned and rapidly injured by arcs. The subject comes up again under the automatic circuit breakers.

Fig. 318 shows a two-pole knife-blade switch for use on switchboards. It has metallic contacts only.

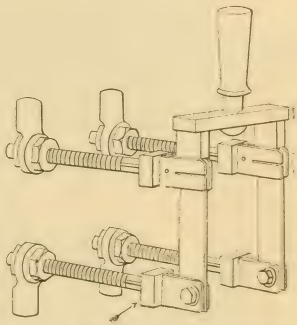


FIG. 318.—TWO-POLE SWITCH.

Oil Switches.—To avoid the formation of arcs, and to insure definite opening of a circuit when the switch is opened, oil switches are employed. These have the part of their mechanism which opens and closes the circuit immersed in oil. This feature insures definite action, and is particularly applied to high-voltage alternating-current switches.

The principle of construction is shown in Fig. 319. On the right and left hand are seen two metallic rods, which descend through insulating blocks and carry springs at their lower end projecting therefrom. Through an insulating block another metallic rod descends between these two, and carries at its lower end a cross piece with beveled carbon contacts C C, facing upward. This rod moves up and down. It is connected to one lead of the circuit; both side rods are connected to the other. When the central rod is raised, its carbon blocks enter between the springs and make the contact, closing the circuit. When lowered, it opens the circuit. A tank of oil, indicated in section in the diagram, contains oil in which the mechanism shown is immersed.

The tank is placed behind the switchboard. A handle on the front of the switchboard raises and lowers the central rod.

Overload and Underload Cut-Outs.—These are of two types, safety fuses and mechanical cut-outs. The subject is more accurately treated than formerly, and cut-outs are now expected to operate with a high degree of accuracy. In ordinary parallel circuits overload cut-outs are placed so as to open their portion of the circuit if the current becomes too strong. In series circuits the cut-outs are arranged to operate by short-circuiting any lamp which may be extinguished. The object is to preserve the continuity of the circuit; it is exactly the opposite of the function of a parallel-circuit cut-out. The underload cut-out operates to open a circuit when the current weakens, ceases, or is reversed. Such an appliance is used in charging storage batteries. If the current falls to zero, it indicates that the counter electromotive force of the battery is equal to the electromotive force of the charging appliance or circuit, and there is danger that it may increase, when current would flow back from the battery and discharge it. The underload circuit breaker opens the circuit as the current falls to zero. Cut-out and circuit breaker are practically synonymous.

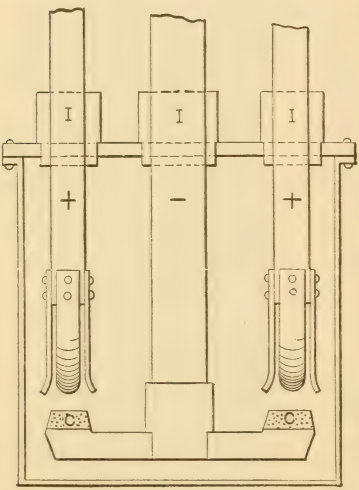
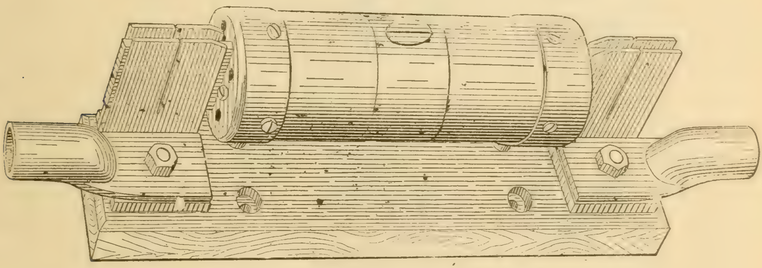
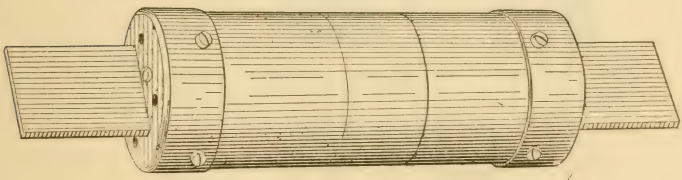


FIG. 319.—OIL SWITCH.

Safety Fuses are strips of fusible metal, whose resistance will develop heat enough to melt when a current goes through it too strong for the rest of the circuit. An ordinary type of fuse is a wire or strip of a specified cross section and length with ears at the ends by which it is screwed down to the circuit terminals. A very usual system is to mount it on a block of porcelain. The lugs or ears at the ends should be clean before it is inserted.

They may be scraped with a knife or may be filed or sandpapered before being put in place. The terminals to which they are screwed should also be bright. In screwing the screws in or out, care must be exercised to avoid making a short circuit with the screw driver. Sometimes the fuse is mounted in a screw cap, and is screwed on a plug in somewhat the way an incandescent lamp is screwed to its socket. Screwing the cap into place makes the contact of the ends of the switch with the circuit terminals. The





FIGS. 320 AND 321 —SAFETY FUSE AND HOLDER.

plug cut-out, as it is called, is a very safe form. If the short circuit still exists, the socket being screwed in the plug will simply blow out again without the operator's incurring any danger. The inclosed fuse is a fusible wire or metal strip embedded in porous non-combustible material within a tube. It is sprung into place between clips in some constructions, which is a very convenient and safe arrangement. The fuse being protected from the air is supposed to be more constant in its action than is the exposed fuse. It is also claimed that it does not blow out so

quickly, requiring a sensible time to fuse. This is an advantage generally, as an excess of current lasting only a second does no harm. The fuse does its work better if it is a little slow about blowing out than if it yields instantly. The inclosed fuse does

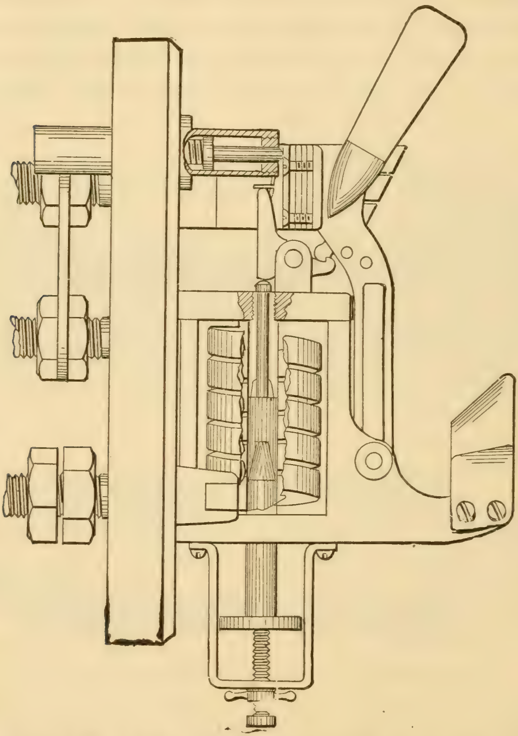


FIG. 322 —I.T.E. OVERLOAD CIRCUIT BREAKER.

not throw melted metal about, which is another advantage. Inclosed fuses in and out of their clips are shown in Figs. 320 and 321. A small wire in parallel with the main fuse is exposed in a little circle seen on the surface of the fuse case. If the fuse melts this also melts, so that the operative knows what has happened.

Overload Circuit Breakers.—These are switches operated by electro-magnets directly or indirectly, so as to open if the current becomes too strong.

The cut, Fig. 322, shows a section of the I. T. E. circuit breaker, whose initials stand for inverse time element. The instrument is shown with the switch closed, and connection made by knife-blade contact. The switch arm is pivoted at the bottom and works in a vertical plane. When it is pushed up into the vertical position as shown, it is held there by a catch, seen just below the handle. The upper end is forced outward by a horizontal plunger actuated by a spiral spring. This is contained in a tube at the top of the apparatus. In the illustration part of the tube is seen broken or cut away, so as to show the plunger. The full current goes through the magnetizing coil back of the pivoted switchbar. The plunger armature of the coil is shown partly below it, and with its upper end within it. Above the armature at some distance from it is a rod which if lifted trips the catch which holds the switchbar in place. Its upper end bears constantly against or almost touches the back of the catch. If the current becomes too strong, the armature is drawn upward with increasing velocity, and strikes the loose plunger a sharp blow, driving it upward. This releases the switchbar by tripping the catch. The horizontal plunger, forced out by its spring, pushes the switchbar backward, breaks the knife-blade contacts, and the bar falls back into a position about 45° above the horizontal, resting on the bracket or stop seen behind it. The position of the armature is regulated by a screw below it with jam nut, all of which is shown in the cut. This can regulate the circuit breaker so that it will open at different current strengths.

It is evident that the greater the excess of current, the more rapidly will the opening occur. The armature is more strongly attracted as it rises. Therefore a very small excess of current will operate it, because if a current is strong enough to lift the plunger from its seat, it will act upon it more energetically from the moment it leaves its seat and rises toward the coil.

The circuit breaker shown in Fig. 322*a* operates on a slightly different principle. If the handle projecting to the right is pushed upward, the circuit is opened. Two contacts, one of

metal and one of carbon, the carbon placed directly above the metal contact, are opened if the handle is pushed up. The contacts are shown closed in the full lines of the cut. The dotted lines show the position of the movable parts of the contacts when they are opened by pushing up the handle. The circuit can be opened and closed by hand. To give it the overload

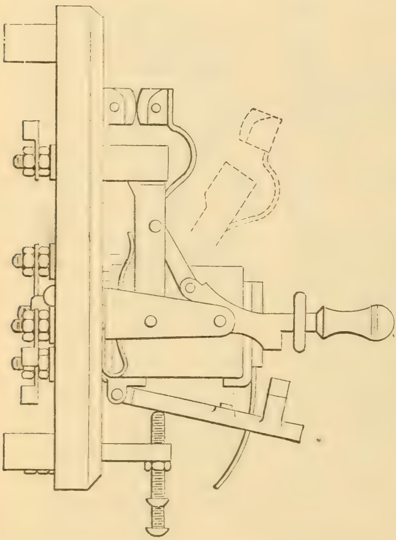


FIG. 322a.—G.E.CO. OVERLOAD CIRCUIT BREAKER.

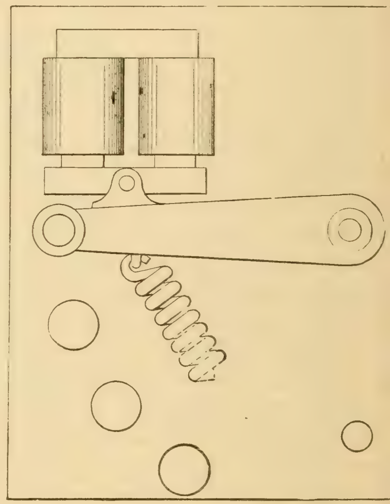


FIG. 323.—MAGNETIC RELEASE UNDERLOAD CIRCUIT BREAKER.

automatic action an electro-magnet is attached to the base of the apparatus, which attracts, when excited, a pivoted armature. When attracted it flies up, strikes the handle, driving it up, and opens both contacts, the carbon one last. The pivoted armature is seen in the cut just below the switch arm and electro-magnet. An adjusting screw is provided to adjust it to act at any desired current within the range of its action.

Underload Circuit Breakers are designed to open a circuit if the current weakens. This is often requisite, especially in charging storage batteries. A weakening of the current indi-

cates increased counter electromotive force in the battery. If this increases beyond a certain amount, the battery will discharge itself through the dynamo and drive the latter as a motor.

Magnetic Release Underload Circuit Breaker.—This is a form used often on motor starting boxes, as explained elsewhere. The illustration, Fig. 323, shows a switch-arm held in place by an electro-magnet against the attraction of a spring which pulls it back. A series of contact studs are shown. In the position shown in the cut, one is under its end, and current goes through the magnet. If the current weakens, the spring will prevail and will jerk the handle back and open the circuit. The spring is not drawn of the full length. Often a spiral spring like a heavy clock spring is used at the pivot end of the switchbar instead of such a one as that in the figure.

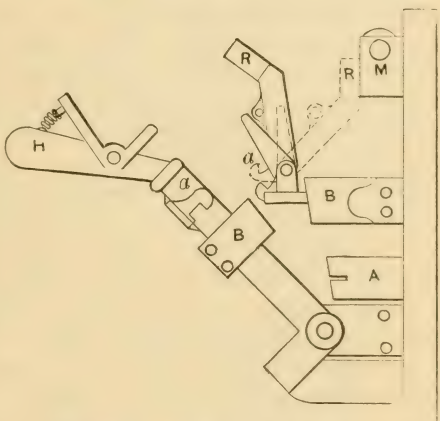


FIG. 324.—UNDERLOAD MECHANICAL RELEASE CIRCUIT BREAKER.

Mechanical Release Underload Circuit Breakers.—These are constructed on the lines of the overload circuit breaker just described. The principle is shown in Fig. 324. A pivoted bar carrying an armature R is held in the position shown in the dotted lines against a spring, omitted in the cut, by a magnet M actuated by the working current. When the current ceases, the magnet releases its armature, which, drawn back by the spring, trips the catch *a* and releases the switchbar. Often both overload and underload coils, each with its own tripping mechanism, are embodied in the same switch. To release at no load, the magnet is in series with the main current. At the handle end of the switchbar is a pivoted lever. This is pulled back by hand when the switch is to be set. Its projecting end pushes up the bar,

so that its armature R is pushed up against the magnet M. The catch *a* then locks and the pivoted lever at H drops out of action. A is a metal contact and B B are carbon contacts. The contact A opens first, and then B B open. This breaking the contact on carbon is done to avoid the formation of a metallic arc on the break, as spoken of in the case of switches.

Reverse Current Circuit Breaker.—In this type the contact is kept closed as long as a difference of potential exists on the line, although it may be on open circuit. A shunt coil surrounds the magnet core, to give the reverse current release. If any potential difference is maintained on the leads of the circuit, a current goes through the shunt circuit and keeps the magnet excited, so that it cannot release its armature. A reversal of current demagnetizes it for an instant; during the change of polarity the armature drops and strikes the switchbar catch. The bar drops and opens the circuit.

Combined Circuit Breakers.—It is very usual to combine two circuit breakers in one, an overload and underload one, both actuated by the same outer circuit. Such circuit breakers as shown in Figs. 322 and 324 are often combined in one.

Other contacts than the knife blade are used. Sometimes a series of leaves of laminated copper slightly bent, something like a carriage spring, are arranged to make contact by pressing their ends against a flat surface of copper.

Circuit Breakers as Switches.—Frequently circuit breakers are used as switches, regular switches being dispensed with. Whole switchboards are fitted up in this way.

Alternating-Current Potential Regulator.—This consists of an induction coil whose secondary is tapped at a number of points. For each tap a contact is provided on the dial face of the apparatus shown in Fig. 325. The contacts are arranged in a circle, and an arm turns on the same center, so as to make connection with them in so doing. The arrangement forms a multipoint switch. By cutting in or out parts of the secondary by means of this switch, the potential of the secondary circuit is changed.

The potential of feeders is controlled by the regulator, which adds its voltage to that already impressed by the alternator upon the feeder circuit.

Reversing switches are provided on the faces, so that the potential of the regulator may work in counter and lower the voltage of the feeder circuit if this effect is required.

One lead from the generator bus-bar goes straight to the district. The other lead goes to the reversing switch, and passes through some of the turns of the secondary of the regulator coil. The number it passes through depends upon the position of the

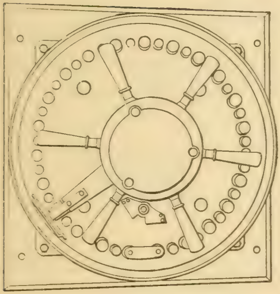


FIG. 325.—ALTERNATING CURRENT POTENTIAL REGULATOR.

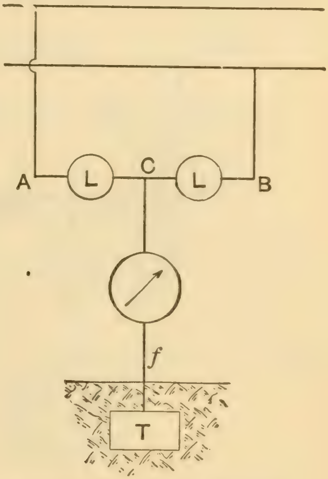


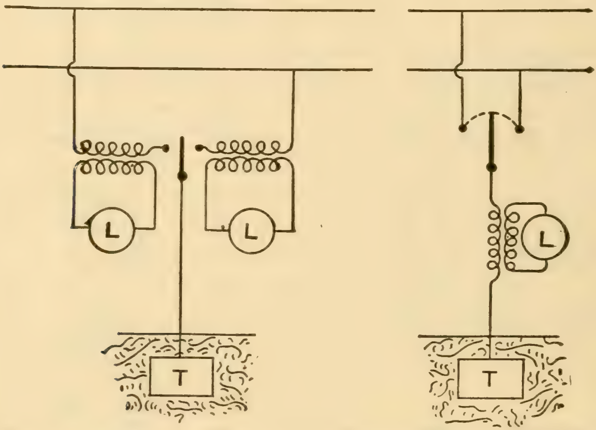
FIG. 326.—DIRECT CURRENT GROUND INDICATOR.

multipoint switch bar. If the switch is set in one direction, the regulator adds potential to the circuit. If set in the other direction, it subtracts potential. The primary coil is connected across the two main leads before the regulator is reached.

In some stations the generator is run at potential sufficient only for the line having the smallest drop, and regulators are used to add to it. The action is like that of boosters in direct current work. Sometimes the original potential is enough for the highest drop of the system, and the regulator with reversed switch lowers it, acting like a crusher in direct-current work.

Direct-Current Ground Indicator.—If two wires of a lighting or power circuit, shown in Fig. 326, are connected with each other through two lamps, L L, each one of the voltage adapted to the circuit, they will show a dull red. This is because being in series they will receive far too little current. Their combined voltage is twice that of the circuit. From the conductor at C between the lamps a connection *f* is made to the ground. A ground plate or water pipe may be used for this purpose.

If there is no ground upon the circuit, the lamps will take one-



FIGS. 327 AND 328.—ALTERNATING CURRENT GROUND INDICATOR.

half their normal current, and will show a dull red as described. If a ground should occur on either line, one of the lamps will be short-circuited by the accidental ground and the ground between the lamps and will decrease in brightness, while the other will increase perhaps nearly to its normal. Generally speaking, the lamp which is reduced in illuminating power is the one connected to the grounded line.

Alternating - Current Ground Indicator.—Alternating-current lamps in permanent connection are not favorite ground indicators, as they necessitate the grounding of the circuit. By a switch and transformers lamps can be arranged to show a ground whenever

the switch is closed. The arrangements are shown in the diagrams, Figs. 327 and 328. One embodies the use of two coils and two lamps, L L; the other that of a single lamp, L. The grounding is indicated by T. The single-lamp arrangement does everything which the double-lamp arrangement does.

Ground Alarm.—Neither of these is an alarm properly speaking. They disclose nothing until the switch is closed. This is an undesirable feature. The next arrangement, Fig. 329, is a constant-alarm apparatus. At C C′ are two plates of metal forming condensers. They are connected through m n as shown with a telephone t on the line going to the ground T. As long as there is no ground on the line, no current goes through the telephone. If a ground occurs, a current goes through it, causing it to produce a humming sound loud enough to be heard through a good-sized room.

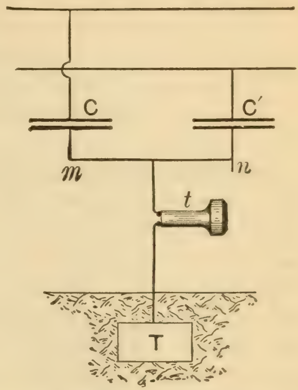


FIG. 329.—TELEPHONIC GROUND INDICATOR FOR ALTERNATING CURRENT CIRCUIT.

CHAPTER XXVII.

VOLTMETERS AND AMMETERS.

The Voltmeter is a galvanometer whose scale is graduated to read directly the potential difference at its terminals in volts. Certain conditions which it has to fulfill are determined by the use it is to be put to. It must be so constructed as to give the voltage between different points of a circuit over which a current is passing. This it must do without affecting appreciably the current. As it has to be connected in parallel with the portion of the circuit to be tested, it follows that a certain proportion of the original current will pass through the voltmeter, and the main current will be diminished by that amount. Therefore it must operate with an exceedingly small current—one so small that it will count for nothing.

Voltmeters are used principally in engineering practice and on reasonably large current circuits. The current which goes through the voltmeter in such cases is treated as infinitely small. Other cases arise in laboratory practice where the current passing through the coil of the instrument has to be taken into consideration.

One type of voltmeter is actuated by coils of wire through which a very small current passes. The wire of the coil is exceedingly thin, and the apparatus is so delicately made, balanced, and journaled that it operates under the effect of an almost infinitesimal current.

The elements of the Deprez-D'Arsonval galvanometer embodied in a portable instrument constitute the essential parts of the voltmeter generally adopted in American practice. The field is established by permanent magnets, with a circular opening between the poles for the coil to rotate in. Within the coil, and concentric with it and with the cylindrical opening, is a cylinder

of iron, which operates to reduce the air gap, thereby intensifying the magnet field. The iron cylinder is fixed in position. This leaves an annular or ring-shaped opening between the core and the pole pieces, unobstructed except where the support of the core comes. This only takes up a few degrees of the circle. The coil turns in this space. In Fig. 330, SS and NN indicate the field poles, P P the pole pieces, and the cylindrical core is shown between them. The coil is also indicated. It moves freely in the space between core and pole pieces, touching neither. There is no difficulty with the core support, because the coil never turns through a full half-circle, and therefore never touches the support. To understand clearly the relations of core coil and pole pieces, Fig. 468 on page 611 may be referred to. This shows the Depréz-D'Arsonval galvanometer, in which the same system of field, stationary core, and revolving coil is used that appears in the type of voltmeters described here.

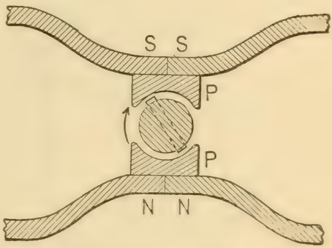


FIG. 330.—FIELD OF THE WESTON VOLTMETER.

In old practice the voltmeter was a high-resistance galvanometer with a compass needle actuated by the earth's field and by the coils of the instrument. Such a galvanometer had to be placed horizontally with its needle in the magnetic meridian when no current was passing. The modern instrument is independent of the earth's field, so that it can be set up without regard to the points of the compass, and vertically or at an angle.

Weston's Voltmeter.—This instrument is very extensively used. Its moving part is a small rectangular coil of wire carried on a shaft whose ends are supported by jeweled bearings. To the ends of the shaft are attached the inner ends of spiral springs, exactly like the balance or hair spring of a watch. The ends are insulated from the axle to which they are attached, and one end of the coil wire is connected to the inner end of one spring and the other end to the inner end of the other spring.

These connections are electrical, and the springs serve to conduct the current to the little coil without preventing it from rotating as the current passes through it. They are leading-in springs, in the sense that the platinum wires in an incandescent lamp are leading-in wires.

If a balance wheel of a watch were replaced by the coil and two hair springs were attached to the axis, one at its top and one at its bottom, it would give the mechanical combination of the apparatus. It is shown in Fig. 331.

The field is that of a horseshoe magnet strengthened by a cylinder of iron held within the coil and concentric with it as regards its axis of rotation. The cylinder is carried by an arm extending from the base or frame of the instrument. It is so placed as not to interfere with the swings or partial rotations of the coil.

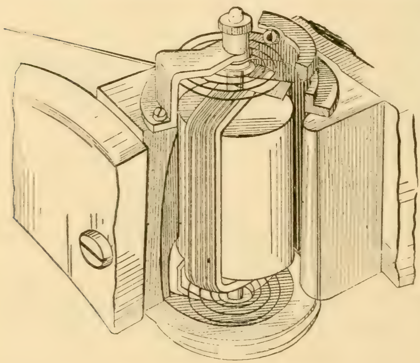


FIG. 331.—CORE, COIL, FIELD POLES AND LEADING-IN SPRINGS OF WESTON'S GALVANOMETER.

The instrument has a long index whose end moves over a graduated scale, the arc of a circle, and divided into divisions representing and calibrated for volts. The soft-iron core and the shape of the pole pieces secure a uniform field and tend to give a uniform motion for increase of current in the working coil.

Damping Coil.—To render the instrument "dead-beat," which means that it shall at once give its reading without having its needle swing back and forth a number of times before coming to rest over the proper mark on the scale, a special damping coil is used. This consists of a coil of insulated wire short-circuited on itself. Over this is wound the active winding, which consists of a number of turns of fine copper wire, whose ends connect with the springs. This double coil is mounted in the field, and its sides move through the annular space between the soft-iron fixed core

and the magnet poles. As it moves under the influence of a current passing through its active coil, eddy currents are induced in the closed circuit of the damping coil, and these oppose its motion and thus prevent swinging back and forth. The instrument goes at once to its proper reading, and shows the voltage at once.

Air-Vane Damping.—An aluminium vane is sometimes attached to the index. As the latter moves, it sweeps the vane through the air. The resistance of the air operates to mechanically damp the movements of the index, and to make it still more aperiodic.

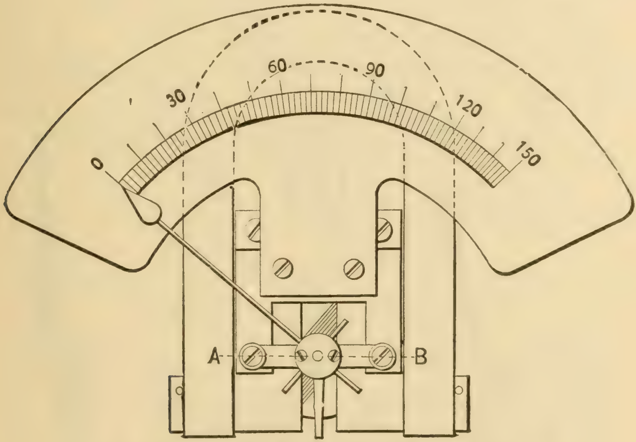


FIG. 332.—PLAN OF THE EMPIRE VOLTMETER.

The critical point about calibrated instruments of this type is to secure a permanent and unchanging magnetic field. This depends on the permanent magnets retaining their magnetism unchanged, year after year. To secure this feature, they must be made of a proper quality of steel. Much secrecy is observed as to this point. They also are not magnetized to saturation; about three-quarters saturation is good practice.

Empire Voltmeters.—The cuts, Figs. 332 and 333, show the construction of the Empire voltmeter. Its general construction recalls the D'Arsonval instrument more than does that of the Weston voltmeter. The characteristic feature is that the needle is

carried by straight phosphor-bronze wires kept strained by spiral springs. These wires by their torsion act to keep the coil in a neutral position, and to bring it back to zero if it is turned away from it. They are also the leading-in wires for the current.

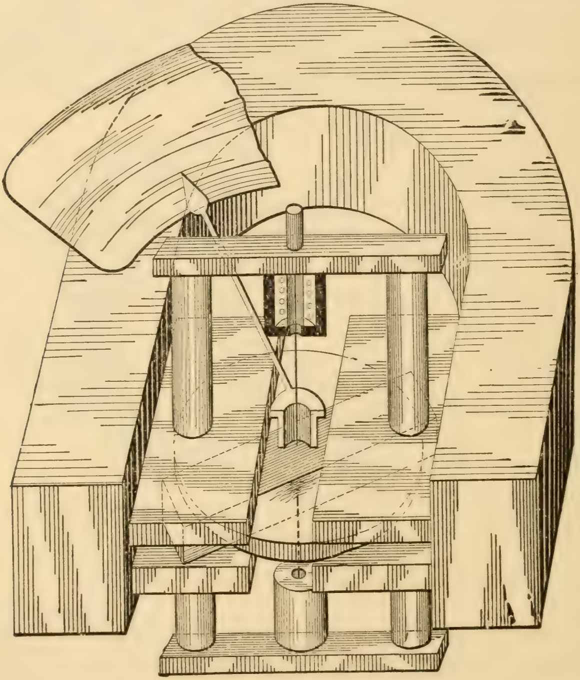


FIG. 333.—THE EMPIRE VOLTMETER.

From the inner surface of the field-magnet poles four flat plates of iron project. These form a strong field, made still stronger by a disk-shaped core supported between them. The coil includes the disk within its open center, but touches no part of the field. The suspension wires, which are also the leading-in wires, as stated above, are kept strained by springs contained in little tubes at the opposite ends of the support. Standards attached to

the four pole pieces carry cross pieces, to which the spring supports of the suspension wires are attached. The connections of the instrument are omitted in the diagram, which is designed to show the characteristic features only.

Graduation of Voltmeter Scales.—The instrument is put in parallel with a standardized voltmeter, and the value of its full reading is noted. This may read widely different from the truth. Suppose the scale is to be graduated to 150 volts, and that 30 volts bring the needle to the end of the scale as yet unmarked. At this point a mark is made. The potential is now lowered to 28 volts, and another mark is made, then to 26 volts, and so on. This gives fifteen divisions on the scale. Each division is evenly divided into ten divisions, thus giving 150 divisions. The 150 divisions correspond to 30 volts. Resistance in series with the coil is now placed in the interior of the case, in the shape of spools of fine insulated wire. It is tested and added to or reduced until a potential of 150 volts carries the index exactly to the end of the scale. The instrument is then standardized and ready for use.

General Notes on Voltmeters.—The index is counterpoised so as to be perfectly balanced. Its one end forms the pointer. Its other end, prolonged beyond the suspension axis, sometimes has a thread cut upon its end, on which counterpoise nuts are screwed back and forth to secure perfect balance. Sometimes this end of the index is bent at right angles, and has counterpoise nuts on the bent portion as well as on the straight portion, to give greater power of securing a perfect balance.

To secure an approximately even motion of the pointer, so that a given change of voltage shall cause the pointer to move over the same number of degrees at all parts of the scale, the combined effect of the even magnetic field and of the springs is relied on.

Cardew Voltmeter.—This instrument, which would seem peculiarly well adapted for alternating currents, is not as much used as is Siemens's dynamometer. It is really an ammeter of very high resistance. Its action depends upon the expansion of a wire through which a current passes. This wire expands with heat and contracts with reduction of temperature, and the temperature

changes depend on the current passing through it. These changes depend on the changes in voltage at its terminals, and it is a voltmeter in practice.

In its essentials a wire is attached to a rotating shaft which carries an index. The other end of the wire is attached to a point a foot or more distant from the shaft, and is stretched. As it changes in length, it turns the shaft. The latter is provided with an index, which indicates the changes in length of the wire. The simplest construction has a straight wire stretched through the center of a brass tube.

It has to be calibrated by trial for various electromotive forces. After enough readings for definite values have been found, others may be intercalated between them. If calibrated for continuous electromotive force, its readings for alternating electromotive force will give the effective value.

Its sensitiveness is greatly increased by using a longer wire. To keep the size of the instrument within practical limits, the long wire is carried back and forth over pulleys made of bone.

In a recent example, the wire of platinum-silver alloy was 0.0025 inch in diameter and 13 feet long. It passed up and down eight times. This brought each stretch of it to a length of about 18 inches. The terminals of the instrument connect with the ends of the wire. When connected to the circuit whose voltage is to be measured, the thin wire very quickly acquires the full temperature due to the current produced by the voltage. The thinness of the wire enabling it to grow hot or cold with great rapidity makes it very quick-reading, or almost dead-beat. Such an instrument can measure voltages from 30 to 120 volts. For higher voltages a resistance is added. This is sometimes made of exactly the same wire and stretched through metal tubes, as in the instrument itself.

There is considerable vagueness in the readings near the zero point, and it is considered inaccurate in the upper part of the scale.

In the construction shown in Fig. 334 a long wire C, carried up and down a frame four times, is used. The current passes through this, and its changes in length draw the little pulley at its upper central bend or bight up and down. By wheel mechan-

ism these movements cause an index like a clock-hand to revolve on a dial, which in the cut is facing away from the reader. A pulley P, around which the wire passes and to which it is se-

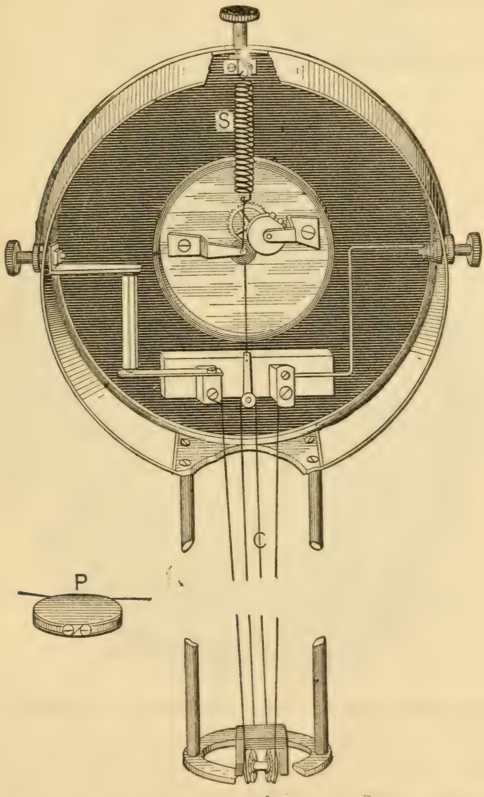


FIG. 334.—CARDEW VOLTMETER.

cured, turns clockwise as the wire lengthens and *vice versa.* This pulley actuates the index. The spring S drags the pulley around clockwise; the contracting wire drags it the other way. A larger view of the pulley P is given, to show how the wires are attached to it. The index and scale are omitted from the cut.

Hot-Wire Instruments.—The Cardew voltmeter is the parent of the hot-wire instruments. It has tended to go out of use of late years. It is affected by alternating as well as by direct currents, and this operated to keep it in use. Hot-wire instruments have had quite extensive application and are still in use.

The Stanley Hot-Wire Voltmeter.—A wire is secured across

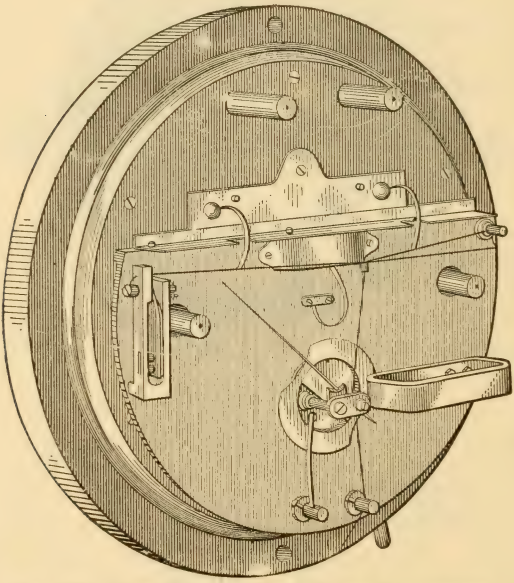


FIG. 335.—THE STANLEY HOT-WIRE VOLTMETER.

the upper part of the instrument, and is held horizontally in general position. Two leading-in springs or connections descend from above and carry current to it, so that the current passes through the few inches of wire between the ends of the leading-in connections. From the center of this actuating wire another wire descends to the bottom of the instrument, and is secured there. This wire is approximately at right angles to the actuating wire. To the left of its center is the index with horizontal axle, carrying a pulley or drum fixed to it. A filament from the

center of the vertical wire passes around this drum, and has its other end secured to a spring. Thus this spring keeps the system of filament, vertical wire, and actuating wire in tension. A current passed through the actuating wire heats it and causes it to expand. A very slight expansion causes its center to descend a measurable distance, on the elbow-joint principle. This magnification of motion is repeated by the vertical wire, so that an infinitesimal change in length of the actuating wire by means of the two magnifications causes the index to move a visible distance.

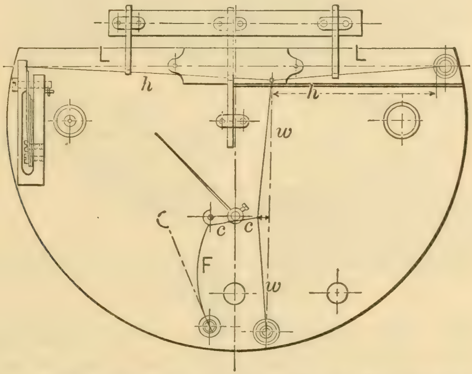


FIG. 336.—THE STANLEY HOT-WIRE VOLTMETER.

The cuts, Fig. 335 and 336, give the general view of the working parts of the instrument.

The hot-wire instrument is unaffected by any electro-magnetic fields, and hence is peculiarly well adapted for places where such fields exist.

Ammeters.—The word *ammeter* is an abbreviation for amperemeter. It is an apparatus for measuring current rate. Any calibrated galvanometer with its scale marked so as to read amperes is an ammeter.

Total-Current Solenoid Ammeter.—The first instruments were constructed so that the entire current passed through the actuating coils. The cut, Fig. 337, shows a modern total-current instrument. A coil of heavy wire is secured to the base of the in-

strument. Its axis is vertical. Through its center a core of iron is free to play up and down, being suspended from the end

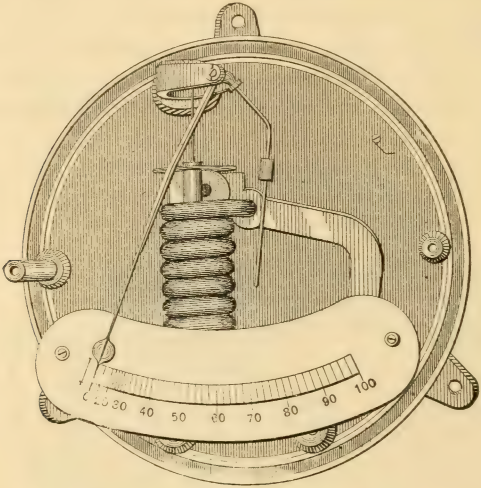


FIG. 337.—GENERAL ELECTRIC COMPANY'S TOTAL CURRENT OR SOLENOID AMMETER.

of a bent lever. The latter has one end prolonged to form the index. As more current passes, the core is drawn downward, and the needle moves over the scale in one direction. If the cur-

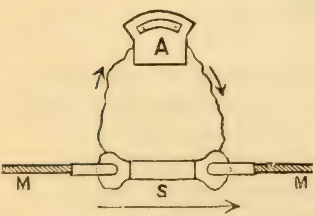


FIG. 337a.—AMMETER CONNECTION WITH SHUNT.

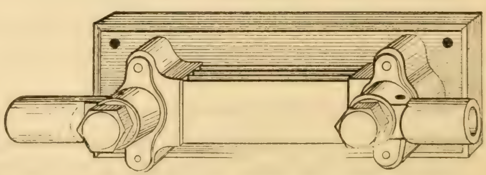


FIG. 338.—AMMETER SHUNT.

rent diminishes, the core rises and the needle moves the other way. Although such an instrument may work with total current, it may be connected in shunt with a conductor, so that

only part of the current will pass through it. In this way it

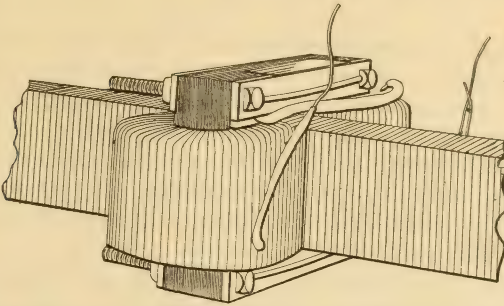


FIG. 339.—TRANSFORMER FOR STANLEY HOT WIRE AMMETER.

can measure a much larger current than its coil could carry.

The coil attracting a plunger is called not quite correctly a solenoid.

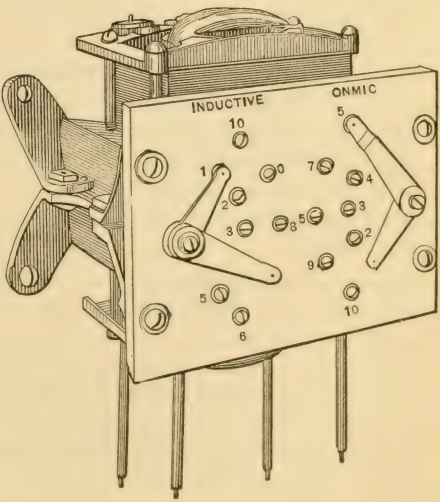


FIG. 340.—ALTERNATING CURRENT VOLTMETER COMPENSATOR.

Shunted Ammeter.—This instrument is a shunted galvanometer, which is calibrated to read amperes. The amperes are those which go through the shunt and actuating coils. The indicating portion of the apparatus is identical with a voltmeter. A heavy shunt sufficient in carrying capacity for the full current is connected in parallel with it, and the calibration is made to fit these conditions. The resistance of the shunt is very low compared to that of the instru-

ment. The diagram of the connection is given in Fig. 337*a*. Various forms of shunt are employed, one of which is shown in Fig. 338.

Transformer Ammeter.—Sometimes on alternating current work a transformer is used to take off current for a voltmeter. By properly proportioning the coils and instrument the voltmeter becomes an ammeter. Fig. 339 shows a transformer mounted on a bus-bar which forms its primary. The terminals from the secondary go to a Stanley hot-wire ammeter. The whole is so calibrated that the readings of the instrument give the amperes passing through the bus-bar.

Wattmeter.—A modification of the construction of the voltmeter gives a wattmeter. In this instrument there are two active coils. One is fixed and the other is movable. The fixed coil increases the field in which the other one moves, and the index readings are a product of the voltage and amperage of the circuit. This multiplying action is in line with the action of magnet poles on each other, the intensity of which is the product of the two intensities, and not the sum.

Pressure Lines or Pilot Wires.—Sometimes small conductors are run to various points in the district, are tapped into the system, and their ends in the station are connected to the terminals of voltmeters. These voltmeters give the potential difference at the distant points to which their wires lead, and the readings of the voltmeters are the factors for operating the machinery in the station.

Compensated Voltmeter.—A voltmeter wound so that its readings practically solve Ohm's law is sometimes employed, connected directly to the mains in the station.

It is a voltmeter containing an auxiliary coil wound in opposition to the main coil. This auxiliary coil is proportioned to the main coil as the feeder drop is to the total potential difference. Such an instrument gives pretty closely the potential difference at the end of the feeder.

Compensators.—A compensator is an instrument for use on alternating-current circuits which indicates voltage between distant points of a circuit. The compensator is installed in the station, it may be a mile or more from the place to which its in-

dications apply. In constant-potential lighting, for which it is specially applicable, pilot wires are sometimes used to give connections for voltage determinations at distant points. Such wires are connected to any desired point on the circuit, are led into the station and there connected to a voltmeter. The readings of the instrument give the potential difference or voltage at the more or less distant point on the circuit from which the wires come and to which they are connected. The compensator gives the same voltage reading without the use of pilot wires.

The Ohmic Compensator includes a transformer whose primary is connected in series with the supply line. The active turns of the primary can be varied by a switch, with a number of contact studs, each one corresponding to and throwing into action a greater or less number of turns in the primary. The secondary, also adjustable, connects with a voltmeter. This connection may be a simple series connection, but sometimes it is connected to an auxiliary coil, which is wound around the voltmeter-actuating coil. This coil is so wound or connected that it opposes the action of the voltmeter coil. The action is like that of the series coil on a compound-wound dynamo. The action of the auxiliary coil increases with the current which passes through the main conductor. This increase of current indicates the need of higher voltage, and to make the voltmeter read the same, the voltage of the circuit has to be increased to make its own proper coil pull harder against the auxiliary coil. Thus, if the voltmeter is kept at a constant figure, more voltage must be given to the line as more current is given it.

By adjustment with the switch and contact plugs the readings of the voltmeter can be made to correspond with any desired drop on the line per given intensity of current.

The Inductance Compensator has a second switch with a number of contact plugs, by which the adjustment for inductance on the line is made, so that the total impedance is taken into account. The instrument is shown in Fig. 340.

A compensator is without action of any appreciable degree upon the circuit. Its action on the voltmeter is such that in order to maintain a constant reading of the voltmeter, the pressure on the circuit must be increased as the current increases.

CHAPTER XXVIII.

DISTRIBUTION.

Two Distribution Systems.—The systems of distribution of electric power may be divided into two main divisions—the constant-current and the constant-potential systems. In the constant-current system the central generators force an unvarying current through the circuit. The potential of the dynamos must rise and fall as the resistance of the circuit varies under different conditions, but the same number of amperes must pass over the line. In the constant-potential system the generators are operated to keep a constant average voltage between the two leads of the circuit; the amperage may vary from almost nothing up to very high values; the station voltage may rise a little in its readings as more current is taken, and may fall a little as less current is taken. These variations compensate for the distance from station to district.

Arc and Incandescent Lamp Circuits.—Lamps and motors are the principal appliances for utilizing electric power. All lamps require a constant current. Arc lamps without individual resistances or reactances can only be operated on constant-current systems. By the use of these individual attachments, which are described later, arc lamps are used on constant-potential systems in very large number. Incandescent lamps can be used on either constant-current or constant-potential system. Motors can be connected so as to work on either system.

Constant-Current Systems.—A constant-current circuit consists of two leads carried through the district to be supplied. The leads are without branches or deviations properly so called; they unite at the most distant part, and form a simple closed me-

tallic circuit. Lamps to be lighted are placed in their circuit, so that the entire current from the station goes through every lamp, and every lamp gets the same current.

The potential on a constant-current system may vary considerably. A lamp may be removed from the line, and the ends of the line may be directly connected without resistance being inserted in place of the lamp. In such case the potential of the lamp will be taken out of the system, and the generators will have to be run at a potential lower than the original potential by an amount equal to that of the lamp taken out. The amperage will be the same as before the removal of the lamp.

The constant-current system is also called the series system; it supplies power by series distribution. It is shown in diagram in Fig. 341.

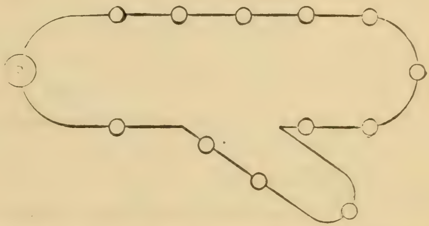


FIG. 341.—CONSTANT CURRENT DISTRIBUTION.

Constant - Potential Systems.—The two-wire constant-potential system begins with two leads, which may divide into any number of branches, each branch consisting of two parallel leads, one from each original lead, and the two leads are not united at their ends, but are on open circuit, except as closed by the lamps or other appliances.

The three and other multiple wire systems do the same, except that instead of two parallel lines three or more as the case may be are carried through the district, branching whenever it is necessary and always on open circuit except for the lamps or other appliances.

The constant-potential system operates by parallel distribution. The lamps or other appliances used are sometimes said to bear to the main leads the relation of the rungs of a ladder to its sides. It is shown in Fig. 342.

Series Distribution.—In series distribution of electric energy the lamps or other appliances to be supplied with current are placed in series with each other. The illustration, Fig. 341,

shows a diagram of series distribution to a number of lamps. The simplicity of the system is obvious. A wire circuit, whose capacity for current is equal to that of a single lamp, can supply any number. There is no question of increasing the size of the wire as more lamps are put into service. In these respects its advantage over the constant-potential circuit is very great. With one exception its limitations are not very great.

Limitations.—One limitation is that each lamp must be constructed for the same current. The potential drop for each one would normally be the same, but this is quite unnecessary. Another limitation is that the total potential difference existing be-

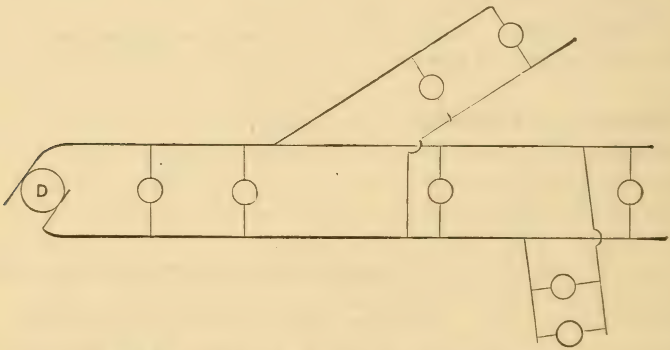


FIG. 342. CONSTANT POTENTIAL DISTRIBUTION.

tween the ends of the line shall not be too great. This is a practical consideration affecting safety to life and possibility of insulating adequately.

The next limitation to be noticed is one which has relegated series lighting to a very limited field. It is not practicable to put out one light without substituting for it some equivalent resistance or inductance. The latter can only be used for alternating-current systems, and high-voltage alternating-current systems are not supposed to have single lamps extinguished by hand, on account of danger to life.

It follows that domestic illumination cannot be organized on the lines of series system of distribution, because single lamps cannot be extinguished. It is not practicable to supply every

lamp in an incandescent lighting circuit with a resistance equal to its own, to be substituted for it when extinguished. If practicable, it would be uneconomical.

Features of Series or Constant-Current System for Arc Lamps.—It will be evident that as every lamp receives the same current, the wire should be of one size throughout. It is also evident that were there one or a hundred lamps on the circuit, the same current would pass and the same sized wire would be required. It follows that the economy in wire is increased by placing as many lamps as possible on the one circuit.

The simplicity of the system is seen in the cut. A single line runs out from the generator and returns to it with as many lamps put on it as the voltage of the machine can take care of. There are no real branches or other complications.

The management is also of the simplest. The dynamo is to be made to supply a constant current and to give the potential required to keep up the current strength.

Fifty to one hundred arc lamps may be placed on one circuit, which may be several miles in length. An ordinary arc lamp would require ten amperes of current and would develop a potential drop of fifty volts.

Calculations.—The calculation for a plain series distribution is simplicity itself. Take as an example fifty arc lamps, each of 10 amperes and 50 volts. By Ohm's law, $R = \frac{E}{I}$, the resistance of one such lamp would be 5 ohms. There is a total drop in the lamps of 50 (volts) $\times$ 50 (lamps) or 2,500 volts to be provided for. Besides this, a current of 10 amperes has to be forced through the line. Take one mile as the length of the line, and assume that a loss of 5 per cent of the lamp energy on the line is admissible. As the current is a fixed quantity, the watts of energy are proportional to the resistance, because $I\,E$ (watts) $= R\,I^2$. The resistance of the lamps would be 5 (ohms) $\times$ 50 (lamps) $=$ 250 ohms. Five per cent of 250 ohms is 12.5 ohms.

Consulting a wiring table, we find that No. 14 wire would give a resistance per mile at ordinary temperatures of 13.31 ohms, and No. 13 wire would give a resistance of 10.6 ohms.

If we wished to have an exact resistance of 12.5 ohms, we could

use both sizes of wire in the line. Calling x the relative length of No. 14 wire required, $1 - x$ will be the relative length of No. 13 wire required. Multiplying the relative length of each wire by its resistance per unit of length, we have the equation

$$13.3x + 10.6\ (1 - x) = 12.5,$$

which being solved gives:

$$x = 0.7 \text{ for No. 14 wire and } 1 - x = 0.3 \text{ for No. 13 wire.}$$

Multiplying each factor by its resistance, we have

$$\begin{array}{l} 0.7 \times 13.3 = 9.31 \text{ No. 14.} \\ 0.3 \times 10.6 = \underline{3.18} \text{ No. 13.} \\ \qquad\qquad\quad\ 12.49 \end{array}$$

The decimals 0.7 and 0.3 refer to a unit of 1 mile, and multiplying 5,280 feet (the feet in one mile) by them, we have:

3,696 feet of No. 14 wire.
1,584 feet of No. 13 wire.
5,280 feet or 1 mile.

But it would be unnecessary to work so close as this. Mechanical considerations apply also under the head of good practice. No. 8 wire is the smallest that is approved on arc-light circuits. If the mile of wire were of this size, its resistance would be about 3.3 ohms. This would bring the energy absorbed by the line to $\frac{3\ 3}{x\ 50} = .0132$, or 1.3 per cent of the lamp energy.

Where the percentage is so small, this would be almost exactly the percentage if the total energy of line and lamps together were taken as 100.

Keeping in mind the law that resistance is to be concentrated in the appliances in which heat or light energy is to be developed, the object of keeping the line resistance low is to avoid waste of power on the line.

Advantage of High Potential.—In the early days of electric lighting, a number of deaths occurred from contact with arc-light circuits. The higher potentials involve the greater danger. High potential of a circuit makes the adequate insulation more difficult than it is for the lower voltages. The idea is that it is good practice to keep voltage as low as is consistent with economical installation. In general terms, the high voltages are more economical in the

wire required for the distribution of electric energy. The unit of rate of energy is the volt-ampere or watt. With high voltage the amperes for a given number of volt-amperes will be less than with a low voltage. Thus 100 volts multiplied by 100 amperes gives 10,000 volt-amperes or watts of power, which is also given by 1,000 volts multiplied by 10 amperes. But the larger number of amperes need a larger conductor than do the small number. Increasing the voltage and decreasing the amperage saves capital invested in lines.

Standard Series Lighting Current.—For arc lighting on the series system a sort of standard has been established in the 10-ampere current. A station supplying circuits of this type simply has to send out 10-ampere currents, and as long as they pass to the line, the engineer can be almost certain that all is well in the district. The voltmeter will indicate the extinction of a lamp on the circuit.

Series Incandescent Lighting.—What has been said about arc lighting applies to series incandescent lighting. The lamps are made of dimensions adapted to the current. If the arc-light current of 10 amperes is used, the incandescent lamps must have very thick filaments of length adapted to establish a relatively low potential difference. Thus, were it proposed to put one hundred ordinary incandescent lamps on one circuit in series, the potential difference due to them alone would be over 11,000 volts, and only one-half ampere of current would be required. One hundred thick and short filament lamps, on the other hand, would replace about double the number of arc lamps and would work with the same current and potential difference.

An incandescent lamp for this work passing 10 amperes of current by the expenditure of 10 volts would give at 3 to 4 watts to the candle power about 32 candle illumination. About thirty such lamps would give the light of a single arc lamp of 10 amperes and 40 to 50 volts. The economy is poor, but is offset by other considerations, one of which is the evenness of distribution. A large number of small lamps give a more even light than that afforded by a few more powerful lamps.

For outdoor lighting a 10-ampere, 100 candle-power lamp is a standard.

Film Cut-Out.—In all the series systems the entire electromotive force of the circuit would appear if the circuit were broken. This applies to the three-loop Brush system as much as to any other. This gives a simple method for constructing a cut-out which will short-circuit a broken lamp through which no current can pass. It is called the film cut-out.

The ends of the line connected to the lamp are bifurcated, as shown in Fig. 343. Between the free ends a piece of paper or other film is interposed, the ends pressing against it, thereby sending the current through the lamp. But if the lamp breaks or the filament parts, the voltage due to the entire electromotive force of the system is developed on the two ends of the conductor separated by the film. This is at once pierced, the ends of the conductor spring together, and the current passes. The resistance of the lamp is gone from the circuit, so the current has to be reduced from the central station to save the lamps from overheating, with consequent breaking down.

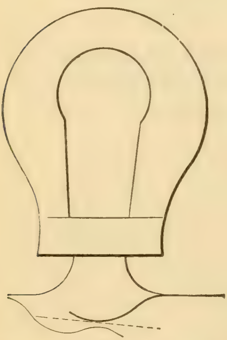


FIG. 343.—FILM CUT-OUT.

Relief Lamps.—On each circuit in the station one or more idle or relief lamps are provided. The attendant watching the ammeters recognizes the breakage and cutting out of a lamp by the increase of current on the line containing it. He then throws one of the relief lamps into the circuit. This reduces the current to the normal, and the broken lamp has to be dispensed with until replaced.

The relief lamp is one of many cases in electric engineering where a lamp is used as a resistance. As a lamp sooner or later burns out, it is an expensive resistance. It has one good side, however. The bright lamp shows that something is wrong. A common resistance would disclose nothing except by the position of its switch.

Multiple-Series System.—Incandescent lamps for street lighting are sometimes made for a lower current, 3 to 3.5 amperes. To enable a larger current to be used, several series of such

lamps may be placed in parallel with each other, as shown in Fig. 344. Each series must be of the same resistance, or it will not receive the proper current. This is termed the multiple-series system. As the same number of lamps are on each circuit, it follows that if the lines connecting them are of identical resistance, the circuit can be operated on constant potential. The property possessed by some makes of incandescent lamps of increasing in resistance as they rise in temperature operates in multiple-series distribution to even the currents received in the parallel lines of lamps. This self-regulating quality works in one way disadvantageously. A very slight rise in voltage makes the lamp work at an exceedingly great economy in consumption of electric energy, but a slight fall dims the light very badly.

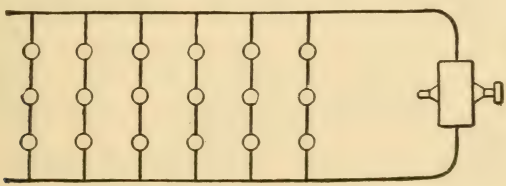


FIG. 344.—MULTIPLE SERIES.

This feature may to some extent provide for the contingency of a lamp breaking down and being automatically short-circuited. The potential drop in that series is distributed among less than the proper number of lamps, and they burn too brightly, but not to such an extent as if their resistance was unaffected by heat. But incandescent lamps as a rule are made without this self-regulating quality.

"Municipal" Series Incandescent Lighting is often carried out on these lines, lamps using 3 to 3½ amperes being employed. Thus with a 10-ampere machine three series could be operated in parallel.

Series-Multiple System.—Another system of distribution for incandescent light is termed series-multiple. In it the lamps are put in parallel in groups, and any number of these groups according to the potential available are put in series. The cut, Fig.

345, shows the arrangement. By selecting lamps of suitable voltage and grouping them in parallel, each group can be made to represent any resistance equivalent to or calling for any current desired. All the lamps in one set must agree in voltage rating—all the station is called upon to give is a constant current of known amount, and the voltage must be enough to produce this current.

It is possible to introduce lamps of different candle-power in this system, provided (*a*) that they are of the same voltage as the others and (*b*) that the current required for each group of lamps is the same. Thus a group could be composed of five 16-candle-power 50-volt lamps or of three 16-candle-power 50-volt

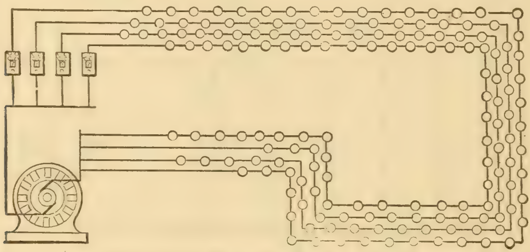


FIG. 345.—SERIES-MULTIPLE CONNECTION.

lamps and of one 32-candle-power 50-volt lamp. Many variations can be made in a group, provided the requirements as outlined are fulfilled.

If one of the lamps breaks down, it will cause the entire group of which it is a part to receive too much current, and will tend to burn out the lamps. This can only be met by having an automatic device of some kind which will switch in a new lamp in place of the other, or which will cut out the whole group. In the latter case the voltage of the system will be suddenly reduced. The station must take care of this, and maintain a constant current or all the lamps will receive too much current and be in danger of burning out.

This system is very little used. The difficulties to be overcome in providing for the contingency of lamps breaking down militate against it.

Objections to Series Distribution.—Series distribution for incandescent lighting involves several features that militate against its use in houses. It requires too high a potential. A high-potential system is a cause of danger to life and property. It exacts that a number of lamps be operated as a unit. A single lamp cannot be turned on and off without disturbing the whole of its group, unless an equivalent resistance or inductance for alternating circuits be substituted. A resistance for every lamp would involve expense in installation, and would absorb just as much energy as a lamp and make no return. An inductance absorbs but little energy and is an important adjunct in outdoor circuit work in alternating-current lighting. But the great danger of a considerable voltage on an alternating-current system absolutely proscribes indoor alternating-current series lighting.

Parallel Distribution is constant-potential distribution. In parallel lighting pairs of mains or wires from the electric station are kept by the station machinery at a constant difference of potential. The lamps are arranged in parallel across them, as has been said, like the rungs of a ladder, as far as their representation in a diagram is considered. Incandescent lamps are constructed for a specific current by being made of adequate thickness of filament and of length sufficient to operate at the desired current with a specified drop of potential. One hundred and ten volts is a sort of standard. For half an ampere of current, the filament has to be of two hundred and twenty ohms resistance. Lamps are made, however, of the most various voltages, and are generally rated by the voltage required to operate them.

If for 110-volt lamps the mains are kept at a constant difference of potential of 110 volts, perfect independence of action of all the lamps is established. They may be lighted or turned off one by one without affecting each other to any noticeable extent. The maximum difference of potential in two-wire circuits is that of a single lamp, which cannot hurt anyone and is treated as a safe potential as far as fire risks are concerned. The electric energy of the system is drawn upon in almost exact proportion to the number of lamps lighted.

The conditions of safety, simplicity, and economy of energy are adequately fulfilled by the parallel circuit.

Disadvantages of Parallel Distribution.—On series connection one hundred lamps could be supplied with current through a wire of one-hundredth the cross section of that required for current for the same lamps in parallel. This is a most important advantage. Heavy currents in electric engineering involve expense of installation at every part, and the interest on the capital invested is to be treated as a part of the fixed charges of the system. The independence of each lamp of the circuit has made the parallel lighting system universal for indoor illumination. Where the street mains already exist, it is used for arc lighting with the attendant sacrifice of economy involved in the use of an individual resistance for each lamp.

Elementary Case of Parallel System.—The simplest case is shown in the cut, Fig. 342, where two leads of even thickness are carried out through the district, and have as many lamps connected across them as they can carry current for. This is wasteful of copper, because the wire which comes between the first lamp and the dynamo determines the size of the outer end of the wire. Current for all the lamps has to go through the wire next the dynamo, while at the outer end current for only one lamp is to be carried, and it is wasteful of copper to use too large a conductor.

The size of a conductor is determined by several considerations. It must carry the current without undue heating. It must be of low enough resistance to pass the current at a low enough drop to secure economical working. The latter consideration is the controlling one, as under its requirements the wire is sure to be large enough to carry the current with safety from overheating.

Potential Drop in Parallel System.—Incandescent lamps for a variation of one per cent down or up in potential drop lose or gain a little over one-sixteenth of their illuminating power. A drop of one volt in a 110-volt 16-candle-power lamp will reduce its candle-power to 15 candles. The consumer's payment is based on light and only indirectly on electric energy. A drop in voltage deprives the customer of the light he is paying for, and the reduction in fuel consumption due thereto is too trifling to be considered. It amounts to failure in carrying out a contract and to injury of the customer without benefiting anyone. The utmost

care should be taken in planning a system to obtain good distribution of potential. Inevitable variations in potential drop can be allowed for by using lamps of different voltage. But after all calculations are made, the results in practice will vary, because various numbers of the lamps may be lighted at once. The calculations have to refer always to all the lamps or to some fraction of their total. Their results will not stand for any other number.

Feeders, Main and Leads.—Districts are not supplied by a single pair of conductors. Feeders run out from the station to points in the district, and are not supposed to be tapped for lamps. These are and should be of uniform thickness. Their ends connect with other wires, called mains. Between the ends of the first lines

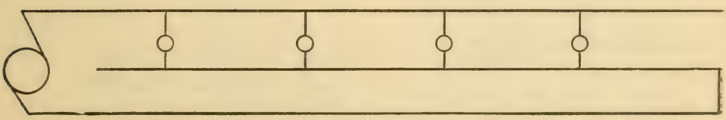


FIG. 346.—LOOP SYSTEM.

of feeders and the lighting mains secondary feeders may intervene. By tertiary and other feeders the system may be made quite complicated. From the mains run other wires called leads, and the lamps are supplied by them.

Classification.—The calculations for supplying a district are based on Ohm's law, and whatever arrangement of mains and feeders is adopted, the calculations are simple. Classification of the systems of supply may be elaborate, but they all are subject to Ohm's law, worked best perhaps by the drop system of calculation.

Loop System.—The loop system of distribution arranges the circuits so that the current for each lamp goes through the same length of wire. There are two loop systems shown in the cuts, Figs. 346 and 347, the straight loop and the spiral loop. If the reader will examine the length of conductor through which the current for each lamp passes, he will find that the lengths are

identical. With a constant current the line drop for each lamp would be the same; for a diminished current, due to the extinguishment of some of the lamps, the line drop varies.

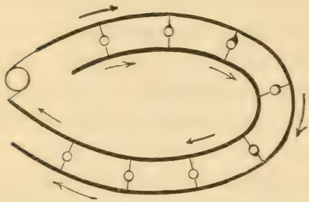


FIG. 347.—SPIRAL LOOP SYSTEM.

The amount of copper required for loop system conductors is greater than in other systems, but the potential is much better maintained than in systems more economical of copper.

Tree System.—In the early installations a pair of mains was carried from the station through the district. From this pair a quantity of minor conductors were carried to supply the lamps. The plan laid out in simplified form resembles a tree, with the station as the root or pot out of which it grows. The two mains are the trunk and the branches, with minor branches to carry the lamps. The cut, Fig. 348, elucidates the origin of the name, the "Tree System," given to it.

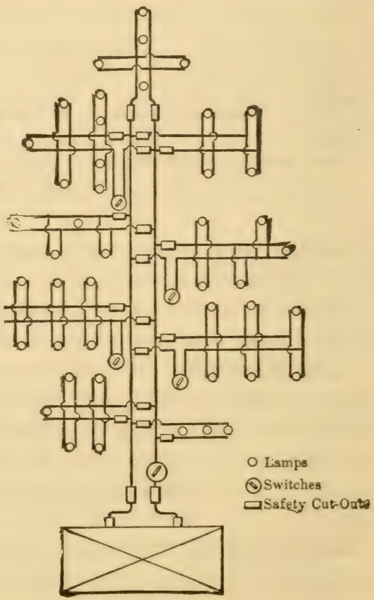


FIG. 348.—TREE SYSTEM OF PARALLEL DISTRIBUTION.

Closet System.—Another system is the "Closet System." In it the lamps are collected into groups. Each group has its own circuit running back to the dynamos. The method is used in interior wiring. An interesting example is shown in the cut, Fig. 349, where two feeders are connected to opposite sides of a double circle of mains, across which the lamps

are connected by their individual leads. In this arrangement the length of main for each lamp is identical. This length is half the circumference of the circle, assuming that the lamps are so close to the mains that the circles of wire virtually coincide. In practice this scheme would be carried out by two more or less irregularly-shaped circuits of mains. The feeders would be tapped in at opposite points.

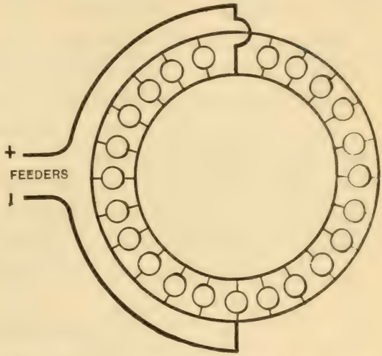


FIG. 349.—CLOSET SYSTEM OF PARALLEL DISTRIBUTION.

In Fig. 350 the closet system is shown as carried out for a number of lamps arranged in four closet connections, with voltmeters and fuses for each group.

Cylindrical and Conical Conductors.—Wire is normally of one diameter throughout, and is almost always of circular cross section. Where such wire is used throughout a circuit or division of

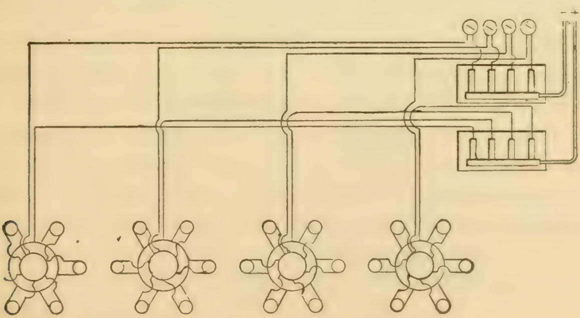


FIG. 350.—CLOSET SYSTEM.

a circuit, the term cylindrical system is applicable. If the wire is reduced in diameter as the distance from the station increases,

it represents a cone, and the term "conical" becomes applicable. The reduction in diameter may be, and practically always will be, by reduction of diameter at various places, so as to constitute a step-by-step reduction. The cylindrical system secures the most even effects as regards potential difference, while the conical system saves copper, and if properly carried out secures good enough results in evenness of potential difference.

It is important to keep in mind the statement of the last paragraph; conical distribution, Fig. 351, does not secure even potential difference between the lines. What it may secure if properly calculated, and if the number of lamps or other appliances assumed in the calculation are operating, is an even potential drop per unit length of line. A drop of this description is simply to be

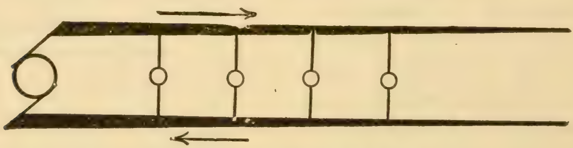


FIG. 351.—CONICAL MAINS.

accepted as an indicator of good practice and as giving a basis for calculating the sizes of conductors.

Calculation for Conical Conductor.—Assume that lamps to be supplied by a main can be divided into three groups for the purposes of the calculation. Let the initial difference of potential be 115 volts. Suppose the first group of lamps are of an average voltage of 114 volts, the next group 112 volts, and the last group 110 volts. The wire is to be reduced in two steps. What should be its resistance at the three divisions? Suppose 50 lamps are in the first group, 60 in the next, and 30 in the last, and that each lamp takes ½ ampere of current.

The total current is $\frac{50 + 60 + 30}{2} = 70$ amperes. By Ohm's law $R = \frac{E}{I}$ and substituting we have $R = \frac{1}{70}$ ohm. This is the resistance of the first portion of the mains, or 1/140 ohm for each lead,

to give a drop of one volt for the 114-volt lamps. The next section has $\frac{60 + 30}{2} = 45$ amperes to supply at a drop of 2 volts; its resistance is $\frac{2}{45}$ ohm, or 1/45 ohm for each lead. The third has $\frac{30}{2}$ $= 15$ amperes at 2 volts, giving a resistance of $\frac{2}{15}$ ohm for both leads. In diagram the above conditions would be indicated as in the cut, Fig. 352.

Suppose that each section of conductor is of the same length, and that it was a cylindrical conductor, one of the same diameter throughout, and that the diameter was that of its first or largest section. The drop for the first group of lamps would be

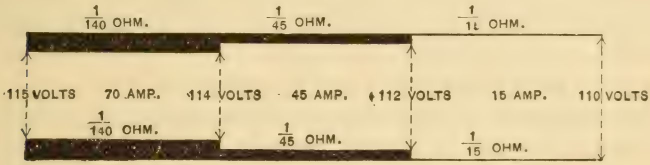


Fig. 352.—Calculation for Conical Main.

one volt as before; for the second, by Ohm's law, $E = R\,I$, it would be $\frac{1}{70} \times \frac{60}{2} = \frac{30}{70}$ volt; and for the third $\frac{1}{70} \times 15 = \frac{15}{70}$ volt. The total drop from the station for the second group would be $1\frac{30}{70}$ volts; for the third group $1\frac{30}{70} + \frac{15}{70} = 1\frac{45}{70}$ volts for the maximum drop of the system, instead of 5 volts as before.

The whole question is to be answered for each case partly by judgment. This is based partly on the cost of copper per pound and the interest charge thereon. As both of these factors vary from year to year, there can be nothing decisive about the result. The lamps to be supplied and their location are other factors also liable to change from time to time, and varying every hour in the numbers in use. Very expensive errors have been made by assuming that rigid accuracy or even an approach thereto was possible in this class of calculation.

The term cylindrical is convenient as indicating that the conductor to which it is applied is of even cross-sectional area. A great many mains have been used which were not of circular cross section, notably in the early Edison installations. The term cylindrical can be applied to them to indicate the feature of even cross-sectional area.

Treating the wire of graduated thickness as if it were a true cone, it will follow from the laws of geometry that with the same initial thickness the conical system will use but one-third the copper that the cylindrical one will. This is because the volume of a cone is to that of a cylinder as 1 is to 3. The total drop in potential in a truly conical system will be twice that on the cylindrical one. If the initial section of the conical conductor is made three times that of the cylindrical one, it is evident, from the proportion stated above, that they will be of equal weight, and calculation shows that in such case the drop of the conical conductors will be two-thirds that of the cylindrical ones.

A diminution in the total drop is advantageous in two aspects. It indicates economy of energy, because less watts are expended on the line. It makes the voltage at the place of connection of each lamp more even along the line. Lamps of a more even voltage can be used.

From the above it follows that conical mains are advantageous if they are not made of too high resistance. The same weight of copper does better work as a conical than as a cylindrical main.

In practice, conductors are invariably reduced in size as they have fewer lamps to supply. Feeders which run out into the district untapped are of uniform size throughout. In electric railroad practice, considerations of strength operate to make the use of cylindrical conductors advisable for overhead work.

Anti-Parallel Systems.—These are systems in which the current enters at opposite ends of the two leads of a circuit. Thus, one lead will receive current at the point nearest the station, the other at the point most remote. This brings about a relatively even potential difference between the two leads, but such connection is not always practicable. It is highly advantageous as compared with the direct connection. The drop takes place from both ends toward the middle.

The diagram, Fig. 353, shows a number of lamps or other receivers or appliances arranged on the anti-parallel system with cylindrical conductors. The characteristic feature of the system

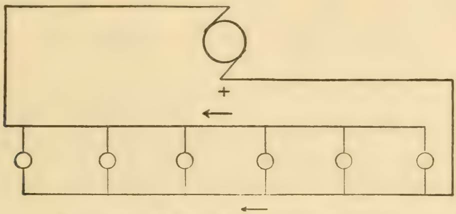


FIG. 353.—ANTI-PARALLEL SYSTEM.

is that no lamp receives the full potential of the system, however near the origin of one of the lines. The nearer it is to the origin

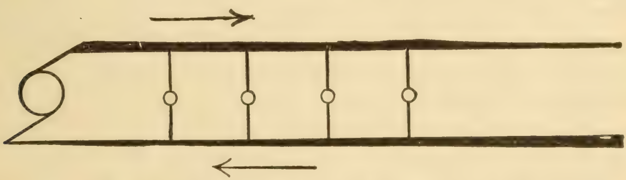


FIG. 354.—ANTI-CONICAL DISTRIBUTION.

of one line, the farther it is from that of the other, and thus a drop inevitably is introduced. Assuming the lamps to be evenly

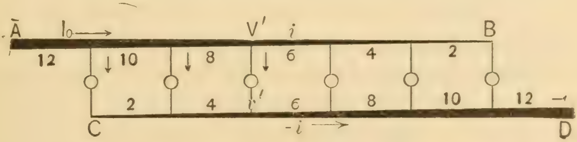


FIG. 355.—ANTI-CONICAL CALCULATION.

distributed along such a line, the end lamps will have the same potential. The greatest drop is in the center of the line.

Finally we come to conical mains in anti-parallel. The cuts, Figs. 354 and 355, indicate the system. On subjecting it to cal-

culation, it appears that when all the lamps or other appliances for which it is calculated are in operation, there is no variation in the potential supplied to each of them. The figures in Fig. 355 indicate the relative areas of the conductors.

All calculations of the systems, it will be understood, were made on the supposition that all the lamps, etc., were in operation at once.

Again we have the 3 to 1 ratio of weights of cylindrical and anti-cylindrical conductors. If the weights of copper employed in a conical and a cylindrical anti-parallel system are the same, the conical is far more economical in energy expended on the line.

Individual Voltages of Lamps.—As by calculation variations in voltage are inevitably found to exist in different parts of an active system, lamps of different voltage are used. A range of 110 volts to 115 volts may be advantageously employed. The low-voltage lamps go to the more distant parts of the system, unless, owing to some peculiarities of the circuits, the drop in the mains brings the place of low potential near the station. In this way the drop in the mains, which increases from generator to the outer limits of the district, is compensated for. By Ohm's law in its form $E = R I$ the drop of any portion of the main is calculated. Its resistance is known as being functions of its length and cross-sectional area. The current it has to carry is known from the number of lamps it has to supply. On multiplying these two factors, the drop for that portion of the main is given.

If therefore a complete system of electric parallel distribution is given to an engineer, he will have, by following out the above method, to determine the special voltages of the lamps to be placed at different localities. It is quite likely that the system may have been laid out with regard to greater consumption in the near future. Original calculations based on the full capacity of the mains must be discarded, as far as lamp voltages are concerned, if only a portion of such capacity is utilized. Calculations based on the actual output and on its true distribution will give the drops in potential for the various points. Then on subtracting these drops from the voltage at the station, the proper voltage of the lamps will be found.

This process has, in a growing district, to be repeated from time to time as more lamps are put in use. The only final calculation is the one covering the district in its final and fixed condition. The calculation is accurate only when all the lamps it provides for are in use.

Relation of Current to Drop.—The drop in voltage varies with the current intensity. This follows from Ohm's law. The current intensity will vary from a very small quantity in the daytime to a relatively high figure called the "peak," during the evening. The drop will on the average vary in like ratio. Therefore it is good practice in operating the works to vary the voltage in such a way as to take care of the variations in drop.

Assume the following case: The current supplied by a given station at the time of maximum demand is 200 amperes. The drop varies from 1 volt to 6 volts at this current, and lamps are distributed to suit these figures. At a certain period 100 amperes are being delivered. The maximum drop varying with the current will be one-half what it should be, namely, $\frac{1}{2} \times 6 = 3$ volts. The average lamp will receive therefore 3 volts more than it should. This condition is met by reducing the initial voltage that much. At another period 170 amperes are being delivered, or $\frac{170}{200}$ of the maximum current. The drop under these conditions is equal to $6 \times \frac{170}{200} = \frac{102}{20}$ or a little over 5 volts. This gives the average lamp $6 - 5 = 1$ volt more than it should receive. To compensate for this, the station voltage may be reduced this amount.

This method gives an approximate correction, which may be put into a simple tabular form for use in the dynamo room. It is only an approximate correction. The saving clause in such cases is that the mains in parallel lighting only give a small drop at the maximum. But a variation of six volts in an individual lamp would be enough to cover the range from the condition facetiously indicated as that of a red-hot hairpin to brilliant incandescence.

The necessity for keeping the maximum drop small makes large mains necessary. The drop question is the weak point in incandescent lighting.

Uniform Potential Methods.—In some small works the generators are run at a uniform potential, one which at full load gives a couple of volts or thereabout too little voltage to the lamps, and at the minimum or no load gives about the same amount in excess. This is a very simple plan, but one not to be imitated.

If the engineer in charge of the station is of the smallest degree of competency, he can run up his voltage as the current increases so as to follow closely a schedule given him by the superintendent.

Automatic Regulation of Voltage can be obtained in some degree by using over-compounded dynamos. A series-wound dynamo working on a parallel circuit will increase its voltage as each lamp is turned on. A shunt-wound dynamo will lower its

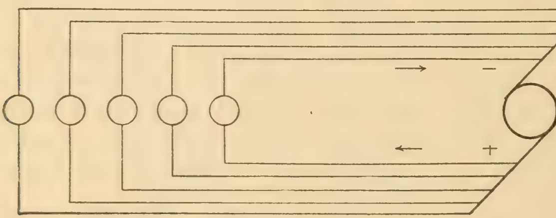


FIG. 356.—INDEPENDENT CIRCUITS.

voltage as each lamp is turned on. It is a simple matter to so wind a compound dynamo that as lamp after lamp is turned on, its voltage will rise just enough to compensate for the natural lowering of the voltage.

Like some other automatic things in engineering practice, this is not as reliable and free from objection as would be desirable.

If a short circuit occurs on the line, the voltage will rise just as if an equivalent amount of lamps were turned on. But the resistance of the short circuit may be so low as to do injury. This contingency can be guarded against by the use of automatic circuit breakers or safety fuses.

Independent Circuits are shown in the diagram, Fig. 356. There are occasions when such a system may be used. As each circuit

gets the same voltage, the lamps or motors have to be chosen with full recognition of this fact.

Feeders.—In electric lighting and power circuits on the constant-potential system, a special class of conductors called feeders are employed, whose function is to increase the evenness of the potential through the system.

Feeders are conductors which, starting from the generating plant or central station, run out into the district and are there connected to the lighting or power mains. No current is supposed to be taken from them *en route*. They go out in pairs for the two-wire system; for other systems three, five, or seven parallel lines are installed. Feeders operate by their direct connection with the power house to raise the potential of the circuit which they are connected to. All of the circuit participates to some extent in the increase. The feeder carries current, and there is a drop of potential in it also.

If there were a given drop in the mains between the power station and point of connection of the feeder, it might seem that a feeder with a greater drop than this one would be useless. But a feeder will always raise potential. It gives a parallel path for current, reducing the current in the regular leads, and thereby raising potential. The drop in a feeder will never exceed that in the mains parallel with it. However small it may be, it will improve the service.

The feeder must not be thought of as delivering station voltage to the circuit. Suppose a feeder had a resistance of 0.1 ohm, and when connected to a circuit at a distant point delivered 100 amperes of current at full consumption. Then by Ohm's law the drop of potential in the feeder would be $E = R\ I = 0.1 \times 100 = 10$ volts. If the station voltage was 125, the feeder would deliver $125 - 10 = 115$ volts to the circuit. If half the current passed through it, its drop would be one-half the above, or 5 volts, and it would deliver $125 - 5$ or 120 volts to the distant circuit.

It follows from this that feeders, unless extravagantly large, do not dispense with station regulation. They are an adjunct to supply circuits, which tends to improve the service. There seems no good reason for absolute abstention from tapping them. In treating of them they are generally assumed to be feeders

only, and not to supply energy except to the circuit where connected.

Several diagrams of feeder connections are given. In Fig. 357 a number of feeders, F, F′, F″, are shown, each with a switch,

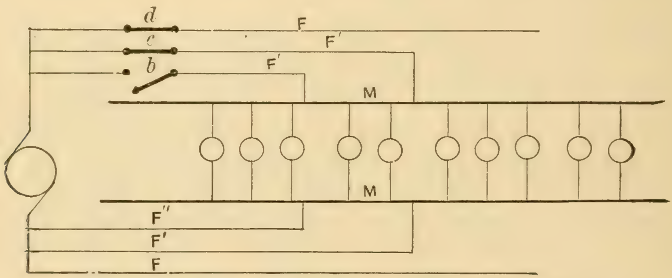


FIG. 357 —FEEDERS WITH INDIVIDUAL SWITCHES.

b, *c*, or *d*, by which it can be thrown out of action when desired. M M are the mains. Sometimes an effort is made to connect feeders symmetrically. This means that each one shall feed the same number of lamps. This plan is of little value, because

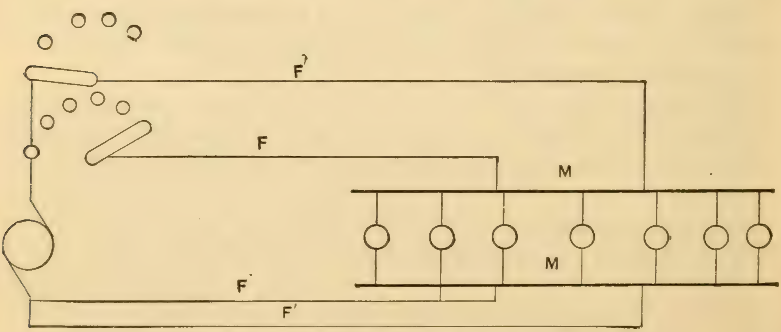


FIG. 358.—FEEDERS WITH RHEOSTATS.

the same number of lamps can never be assumed to be burning at all times. A general estimate is all that can be made.

The next cut, Fig. 358, shows an attempted refinement on the last described connection. Here each feeder has its own rheostat.

This makes it possible to vary the resistance so as to maintain an even potential drop in the feeder. This method is opposed to the general law to the effect that resistance should be concentrated in the lamps, or wherever heat energy is to be used. The putting resistance voluntarily into a feeder or any other transmission line is on its face at least bad engineering. The voltage should be increased or reduced at the dynamo. Resistance such as indicated in the diagram is called "dead" resistance.

Auxiliary Feeder Connections at higher voltage than that of the station dynamo are sometimes used. The next diagram, Fig. 359, shows this method. To the left is the station dynamo

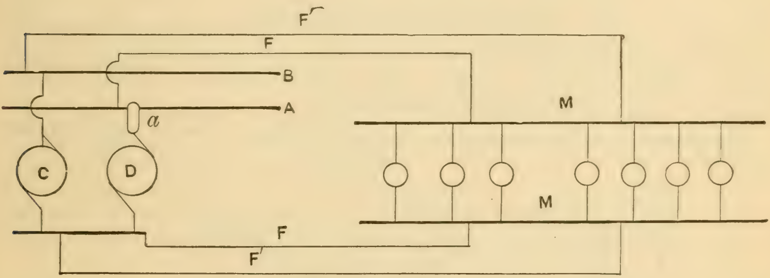


FIG. 359.—AUXILIARY BUS-BAR CONNECTION.

delivering current to the main feeder F′. For auxiliary feeders a special bus-bar is provided. This is connected to a special dynamo D, which maintains any desired potential in the feeder circuit F. A is connected to D by the switch *a*.

Transfer Bus-Bar.—Sometimes a feeder supplied from one bus-bar of a given potential has to be shifted to another at a higher or lower potential. A transfer bus-bar is used for this purpose. In the diagram, Fig. 360, A is a high-potential, C is a low-potential, and B the transfer bus-bar. Suppose that the low-potential feeder M, as the circuit is drawn upon for current in the lighting hours of the evening, has to be shifted from C to A. The switch *c* is closed upon B. At *d* is a rheostat. As shown, the circuit at *d* is open. The arm of the rheostat is swung to the left, thus closing the contact through the resistance of the

rheostat. The switch arm *d* is moved on slowly until an ammeter shows that B is taking all its current from A. This can be brought about by reducing the resistance by moving the switch *d*.

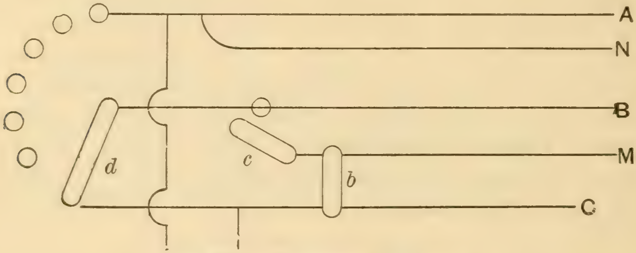


FIG. 360.—TRANSFER BUS-BAR.

The switch *b* is next opened, and *d* is swung to the end of its course, so as to cut out all resistance.

Example.—As an example of parallel and feeder distribution

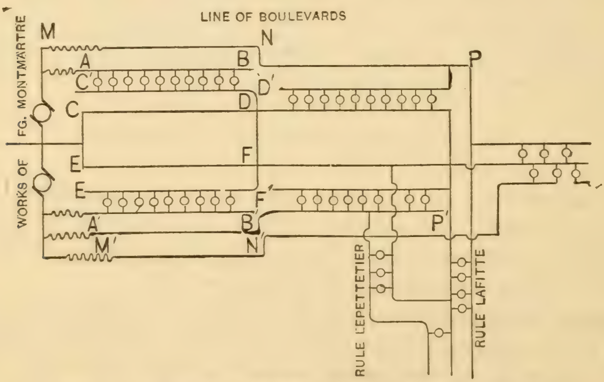


FIG. 361.—EXAMPLE OF PARALLEL DISTRIBUTION.

embodying conical leads, Fig. 361 is given, showing a district of Paris, which illustrates much which has been described.

Feeder Economy.—When capital has been invested in tons of copper in order to keep resistance down all through a lighting district, it seems crude to regulate the action of feeders by volun-

tarily increasing their resistance by a rheostat. It seems still worse to make them absolutely useless by opening a switch, and utilizing an expensive feeder line perhaps only during an hour or two of peak. With rheostats some good is got out of the lines. With an open switch the line does nothing.

It is fair to assume that most stations are operated largely for light. It therefore follows that for some twenty hours out of the twenty-four their mains will be comparatively idle. Hence if a main is switched on for only one hour, it is hardly fair to say that it is idle for $\frac{23}{24}$ of the day. Relatively speaking, it would be fairer to refer its action to the lighting period, and treat it as idle for three-fourths of the time only.

Three-Wire System.—The three-wire system, like the rest of the parallel systems, is a concession in the direction of economy

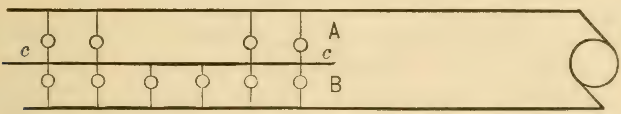


FIG. 362.—THREE-WIRE SYSTEM WITH ONE GENERATOR.

of copper. The direct source of this economy lies in the doubling of the initial voltage of the system. For lamps of 110 volts a potential difference of 220 volts between the mains is employed. The station dynamo may run at 230 volts. A further economy in the expenses of the leads or conductors is based on the probability that lamps can be so distributed into two groups that all the lamps in one group will never be lighted at a time when all the lamps in the other groups are extinguished.

In the three-wire system three leads are carried through the district, Fig. 362. A potential difference of 220 to 230 volts is maintained between two of the wires; the third wire lies half way between the others in potential. The third one is called the neutral wire. One dynamo, as in this cut, or two, as in Fig. 363, may maintain the power.

Saving in Copper.—The saving is due to the fact that the circuit has its two outer leads maintained at double the potential

difference of that which would be required in the two-wire system. Hence for the same number of watts, and consequently for the same number of lamps, one-half the current would be required. The two outer conductors could be made one-half the size of those in the two-wire system. This would be one-half the copper. But the neutral wire has to be provided. This may be

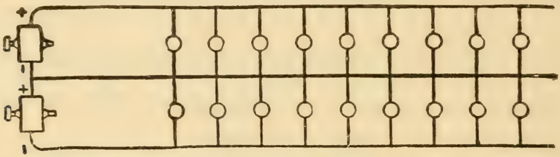


FIG. 363.—THREE-WIRE SYSTEM WITH TWO GENERATORS.

smaller than either of the others, but it is always of some considerable proportion of the size of the main wires.

If the lamps were always lighted in even number on each side of the neutral wire, it could be dispensed with. If all the lamps on one side were lighted and all on the other were extinguished, the neutral wire would have to be as large as the main wire. Its

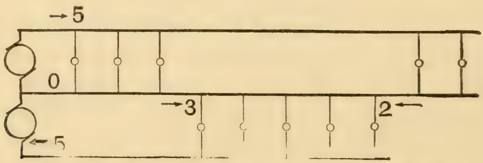


FIG. 364.—ACTION OF THE NEUTRAL WIRE.

relative size is a matter sometimes of calculation and sometimes of judgment.

The diagram, Fig. 364, shows a case typical of the three-wire system. The neutral wire here has two currents going through different parts of it, in opposite directions. It is like two tides coming around an island and impinging against each other. A portion of the neutral wire in this case receives no current whatever, yet other parts of it are passing current and keeping the system balanced.

Two-Dynamo Three-Wire System.—In first-class station work the three-wire system is operated by two dynamos, each of the requisite potential to supply a single set of lamps. The cut, Fig. 365, shows the system. It is clear that each dynamo could supply the lamps between its main and the neutral main. The neutral wire or main connects with a line connecting the two dynamos, one positive and one negative brush, as shown.

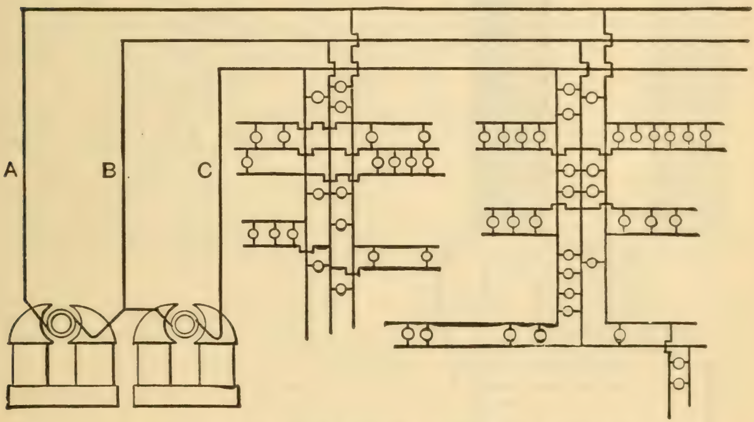


FIG. 365.—THREE-WIRE SYSTEM WITH TWO DYNAMOS.

Single-Dynamo Three-Wire System.—Various modifications of the three-wire system are employed in special cases. One is shown in Fig. 362, in which the neutral wire does not connect with the single dynamo used. This dynamo must have twice the voltage required for a single lamp in addition to that required for the drop.

Three-Brush Dynamo.—Another modification consists in the introduction of a third brush on the dynamo, placed midway between the regular ones. The neutral wire is connected to this brush as shown in the cut, Fig. 366. The system is apt to give a great deal of sparking on the commutator if the two circuits take different currents. The normally idle neutral wire at least supplies a security against the obligatory shutting off of two

lamps at once. Where there is little chance of great inequality between the two groups, such an arrangement will work very well. It is not to be regarded as a standard method, on account of the liability to sparking on the commutator.

Storage Batteries in the Three-Wire System can be used to advantage. The cuts, Figs. 367 and 368, show three-wire systems with storage batteries. When lamps are extinguished, the surplus current from the dynamo goes through the battery and charges it. When the current from the dynamo is drawn upon beyond its fullest extent, the storage battery comes into action, and

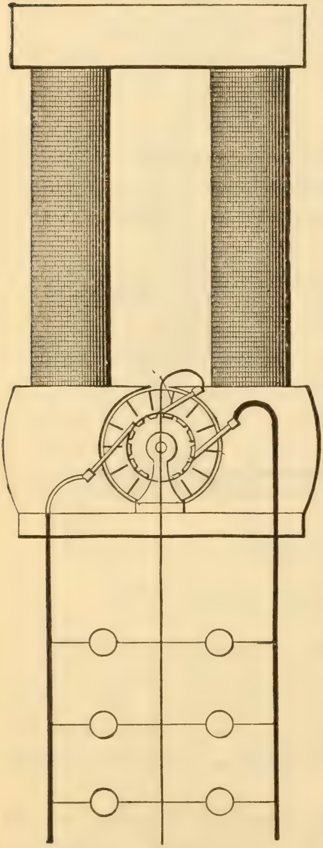
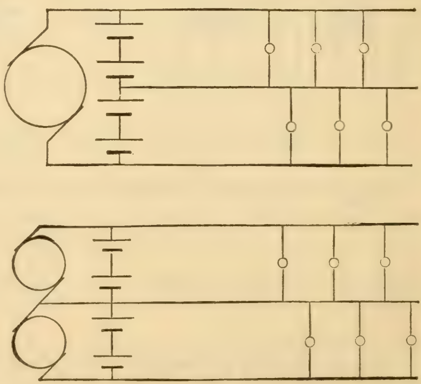


FIG. 366.—THREE-BRUSH DYNAMO.



FIGS. 367 AND 368.—STORAGE BATTERIES IN THREE-WIRE SYSTEM.

supplies the deficiency. Its action is regulated by the use of end cells, counter electromotive force cells, or rheostat, as elsewhere spoken of.

Storage Battery Equalizer in Three-Wire System.—In Fig. 369 the storage battery S is connected to the neutral wire N and to the outer wire M. If lamps are extinguished on one side of the system, the current thus thrown upon N is taken care of

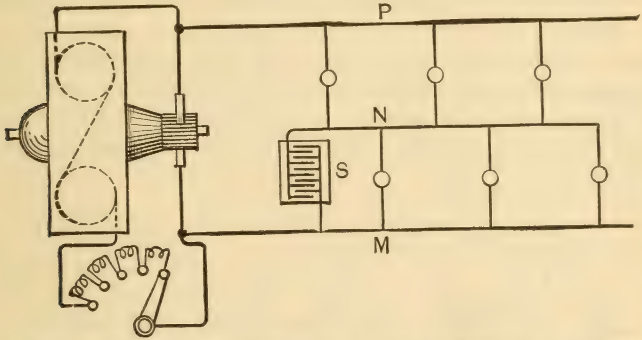


FIG. 369.—THREE-WIRE SYSTEM WITH STORAGE BATTERY EQUALIZER.

by the battery. It will charge or discharge according to which group A or B is using most watts. A rheostat is provided to regulate the dynamo field. The battery could be connected to P in-

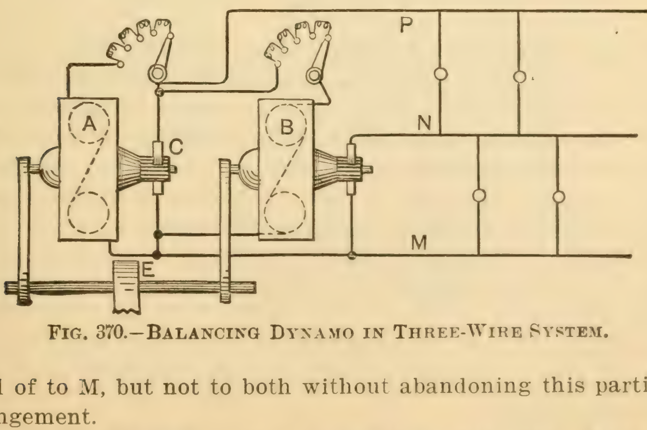


FIG. 370.—BALANCING DYNAMO IN THREE-WIRE SYSTEM.

stead of to M, but not to both without abandoning this particular arrangement.

Balancing Dynamo.—The illustration, Fig. 370, shows two

dynamos in a three-wire system, one, indicated by A, being of double the voltage of B. Both are driven from the same counter-shaft E. At even load on both branches, P and M, the dynamo B runs idle. If the branch P has most load, current going through the neutral wire goes through B and actuates it as a motor. If M has most load, B operates as a dynamo to supply the M side of the system.

Motor and Booster.—In the cut, Fig. 371, A represents a dynamo running at a high enough potential to make the loss between G and R comparatively small. A is in the central station, R and C are in the district. R is a motor, and its functions are to drive the booster C.

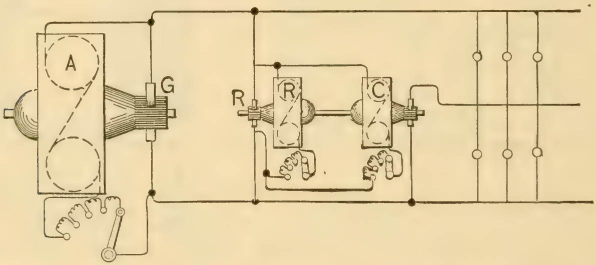


FIG. 371.—MOTOR AND BOOSTER IN THREE-WIRE SYSTEM.

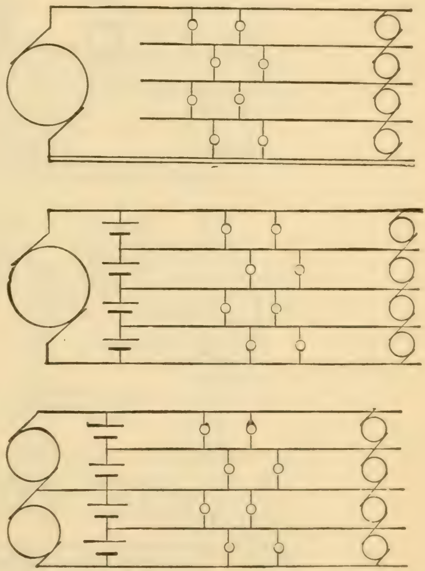
Five and Seven-Wire System.—The three-wire system is the first step in multiple wiring, as a two-wire system does not fall into the category of multiple wiring, where it etymologically should belong. The next step is to add couples of wire. Thus the five-wire and the seven-wire system are developed. In the five-wire system the potential is four times that of a single lamp; in the seven-wire system it is six times that quantity. If standard incandescent lamps are used, the voltage of the systems will be $120 \times 4 = 480$ volts, and $120 \times 6 = 720$ volts, allowing for the drop of the lines.

The central wire is the neutral wire, but the current may be variously divided among the wires by the consumption varying in different groups.

The high voltages are not very safe, and it can be readily seen

that such a multiplication of wires complicates the station machinery and the distribution of lamps on the circuits. The attendant high voltage exacts better insulation and more careful laying of mains and leads. In America the three-wire system has obtained by far the greatest extension. In Europe the five-wire system is used in a number of places.

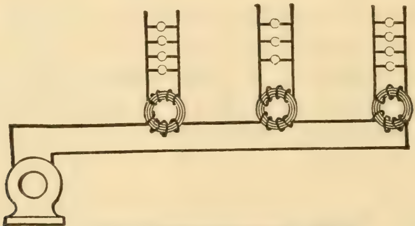
Examples of five-wire systems are shown in Figs. 372, 373, and 374. The last two illustrate the use of storage batteries at the station end of the system. They are susceptible of many variations.



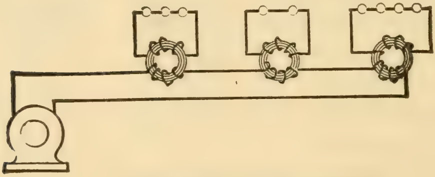
FIGS. 372, 373 AND 374.—FIVE-WIRE SYSTEMS.

High - Voltage Parallel Systems.—The manufacture of 220-volt lamps has been considered a difficult problem to solve under commercial limits. With such, a three-wire system could be operated at 480 volts minimum, reducing the copper used for mains to one-half the amount for 110-volt lamps. Some authorities consider that the three-wire system with 220-volt lamps is destined to prevent the extensive use of the five-wire system. Multiple-wire systems possess a feature which may be of value. There is nothing in the system to interfere with the possibility of connecting apparatus such as motors across from main wire to main wire, thus utilizing the double voltage of the system with the exclusion of the neutral wire. A 220-volt motor can thus be used on a three-wire 110-volt circuit. On a five-wire or seven-wire system the entire potential difference will approximate respective-

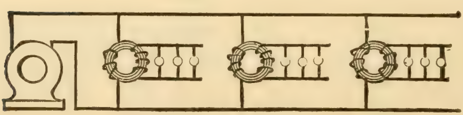
ly 480 and 720 volts. This gives the conditions for a high-power motor with small conductors. The voltage in such cases is about that of a trolley car system, and the system represents a combination of high and low voltage parallel distributions.



TRANSFORMERS ARRANGED IN SERIES, WITH LAMPS IN PARALLEL.



TRANSFORMERS ARRANGED IN SERIES, WITH LAMPS IN SERIES.



TRANSFORMERS ARRANGED IN PARALLEL, WITH LAMPS IN PARALLEL.

FIGS. 375, 376 AND 377.—EXAMPLES OF TRANSFORMER DISTRIBUTION.

Alternating-Current Distribution.—The use of the transformer to change voltage is the characteristic feature of this class of distribution. Fig. 375 shows in diagram transformers in series, each absorbing a portion of the voltage of a dynamo and transforming it into voltage adapted for lamps, which are supplied in parallel from the secondaries. Fig. 376 shows a series of transformers as before, but each one supplying a set of lamps in series. A full parallel system is shown in Fig. 377, where the transformers

are in parallel, their primaries connecting to two leads from a dynamo, and lamps in parallel being supplied from each transformer. The lamps as in both the preceding cases take current from the secondaries. The latter arrangement is shown more in detail in Fig. 378, where arc lamps absorbing 104 volts each are supplied by means of a converter from a 1040 or 2080 volt circuit.

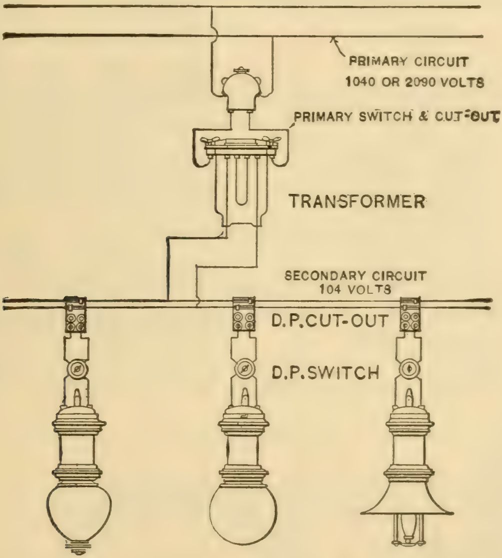


FIG. 378.—TRANSFORMER CONNECTION FOR ARC LAMPS.

Individual Transformers.—Small transformers are used for single motors and lamps. In Fig. 379 is shown a motor supplied from a high-tension circuit by means of a transformer. This and the preceding cut have the names of the different parts noted on the illustration. Although only one motor is shown, the extension of the secondary circuit to right and left indicates that more motors may be supplied by the same transformer.

Choke Coils.—In Fig. 380 is shown a single incandescent lamp carried on a bracket with a receptacle at its base in which there

is a choke coil. This is virtually a transformer without any secondary. It is connected in parallel with the lamp. An alternating current as often thus connected lights the lamp because the inductance of the coil sends current through the lamp. If the lamp filament breaks, the current goes through the coil. Thus the breaking of the lamp does not break the circuit. The arrangement is adapted for lamps in series, as shown in Fig. 381.

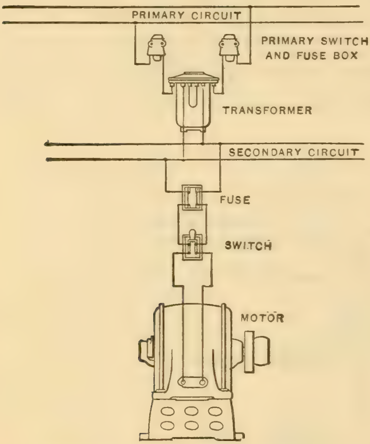


FIG. 379.—MOTOR AND INDIVIDUAL TRANSFORMER.

Y Connection for Alternating Current.—Three-phase alternating current is often distributed by the Y connection, so called because the three leads are connected as if by a letter Y. The diagram,

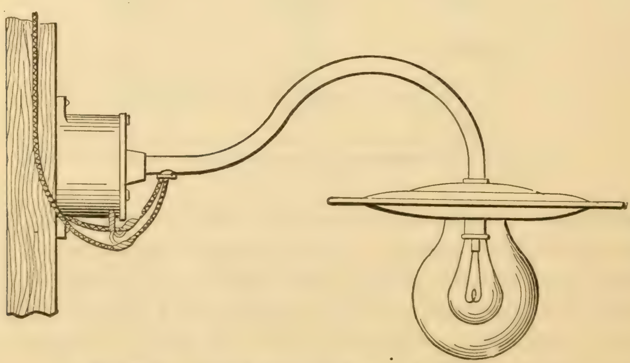


FIG. 380.—CHOKE COIL FOR INCANDESCENT LAMP.

Fig. 381*a*, shows the system. At the generator end the armature windings A, B and C are connected at a central point *n*.

This is described elsewhere under the subject of alternating current generators. From the ends of the three windings three leads are carried through the district and lamps or motors are connected as indicated. A motor is indicated on the right hand with its three armature coils, A, B and C, also connected at a sin-

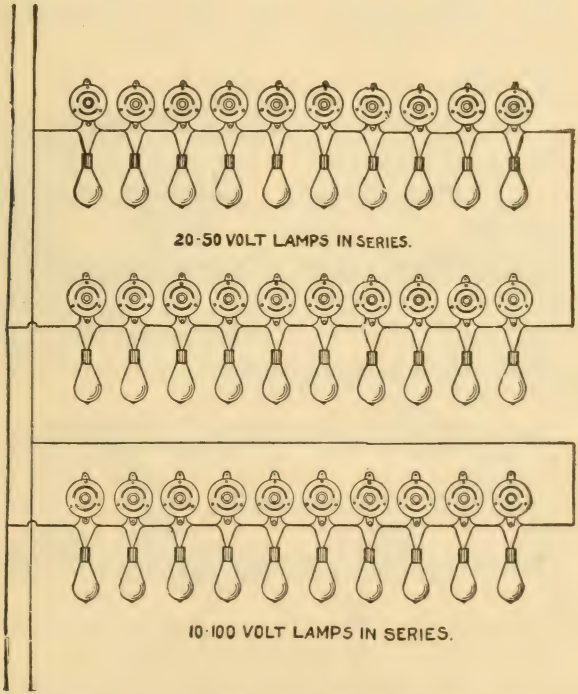
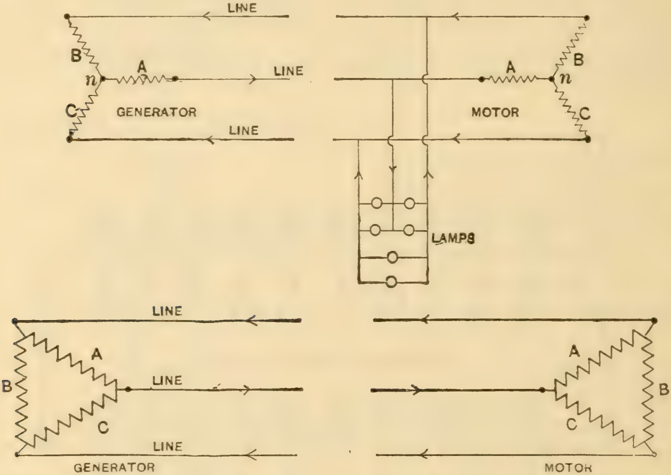


FIG. 331.—INCANDESCENT LAMPS IN SERIES WITH CHOKE COILS.

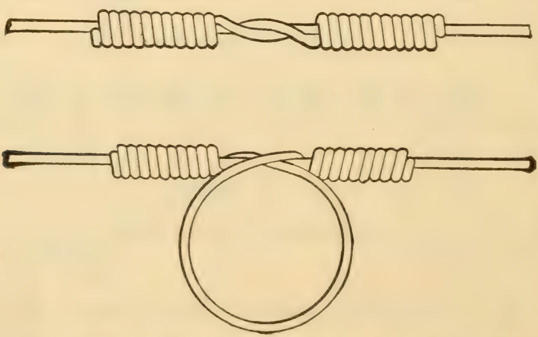
gle point n. The lamps are connected between any two leads as shown. If there are more lamps on one pair than on another the system will be out of balance, and a fourth neutral wire connecting n and n will be required. This is sometimes called star connection.

Delta Connection.—This is also spoken of under alternating

current generators and is illustrated in Fig. 381*b*. A, B and C represent the three armature coils of a three-phase generator and



FIGS. 381*a* & 381*b*.—Y AND DELTA CONNECTIONS FOR ALTERNATING CURRENTS.



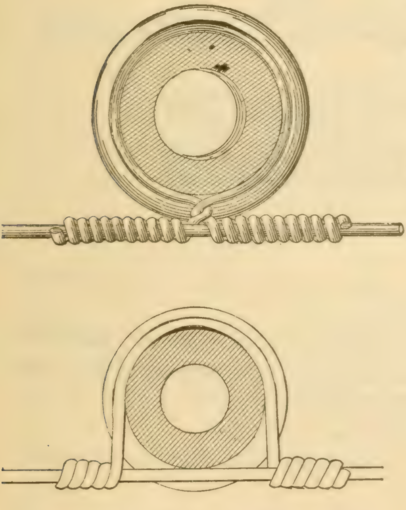
FIGS. 382 AND 383.—IRON WIRE JOINT AND TIE.

motor respectively connected as shown. No neutral wire is used in this system.

Joints in Line Wire.—It is beyond the scope of this work to give the details of line construction, which is becoming more

complicated as aerial and underground distribution systems acquire more extension. In the illustrations, Figs. 382 to 390, some examples of joints and ties in wire conductors are given.

Figs. 382 to 386 show how iron wires are joined to each other and how they are tied to glass insulators. The joint shown in Fig. 382 is sometimes called the Western Union joint. The tie wire in Fig. 383, it will be observed, is carried around the insulator, and its ends are then twisted around the line wire. Other



FIGS. 384 AND 385.—IRON WIRE TIES.

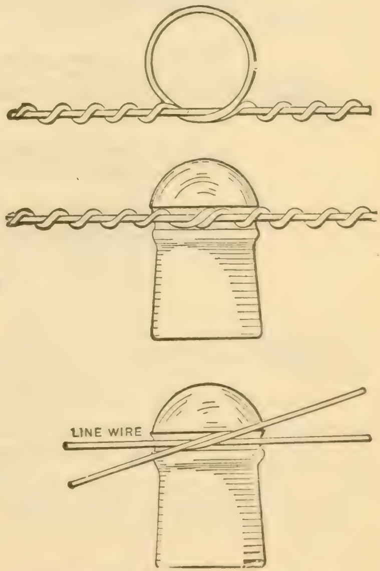


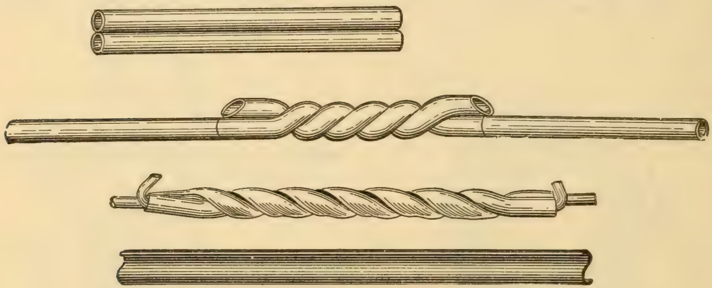
FIG. 386.—PUTTING ON TIES.

ways of tying are shown in Figs. 384 and 385. In one the tie wire does not go entirely around the insulator, in the other it completely encircles it and is twisted once around itself before the ends are twisted around the line wire. Fig. 386 shows the operation of making such joints.

For copper wire, sleeve joints have met extensive use. The Helvin joint was made with a brass double sleeve receiving the ends of the wire. One way of using a sleeve is to twist the ends

of the wires projecting beyond the sleeve around the line wire outside of the sleeve. The ends of the sleeve are closed with solder.

Fig. 387 shows such a double sleeve used in the McIntyre joint. Here the wire is passed well into the sleeve, and then wire and sleeve are twisted together as shown. Sometimes solder is ap-



FIGS 387 AND 388.—SLEEVE JOINTS.

plied, holes being made in the sides of the sleeve to admit the solder.

A simple strip of copper bent so that its cross section is S-shaped is used as in the McIntyre tubular sleeve. It is shown in Fig. 388. A simple joint made with a small wire seizing is shown in Fig. 389. Soldering may be applied to this joint.

Ends of wires in cables are joined by twisting, as shown in

FIG. 389.—SEIZED JOINT.

Fig. 390, care being taken to prevent the wire at the joint in one wire from touching that in another. When ends of cables are to be connected, a lead sleeve is placed over the end of one cable, is pushed back, and the wires are connected and the joints are insulated by paper wrapping or other material. The sleeve is then

pulled over the joint and soldered to the ends of both cables inclosing the joint, so as to make it perfectly water-tight. Such a sleeve soldered in place is shown in Fig. 391.

In Fig. 392 is shown the transposition of wires on a pole top. This is done in order to avoid induction; the induction inevitable when an active telegraph or telephone wire is near another one,

FIG. 390.—JOINING WIRES IN A CABLE.

FIG. 391.—SLEEVE ON CABLE.

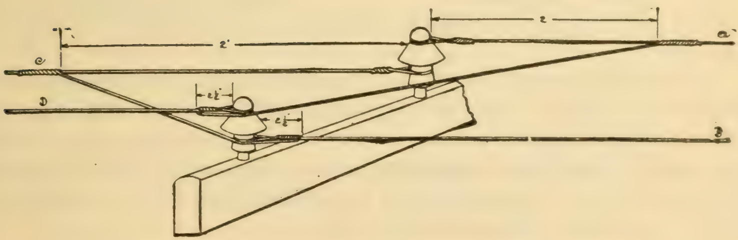
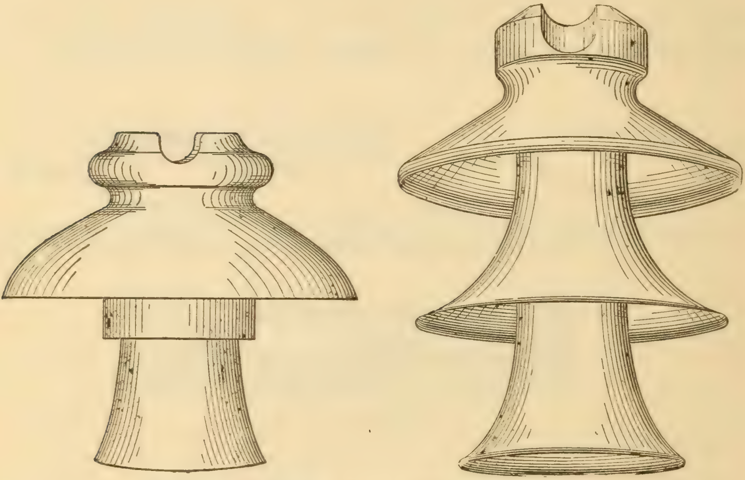


FIG. 392.—TRANSPOSITION IN AERIAL LINE WORK.

being of opposite polarity as the leads are changed. Thus the inductive effect from one length of wire counteracts that from the other.

Insulators.—These are now made in a great variety of forms. As typical of modern practice two insulators are given in the cuts. Fig. 392*a* is an insulator with a groove in its top to carry the wire, and constructed to withstand a potential difference of 80,000 volts. By doubling the projecting flanges or "petticoats,"

the insulator shown in Fig. 392*b* is made, which is good for a potential difference of 120,000 volts. These are extreme cases.



FIGS. 392*a* AND 392*b*.—HIGH-TENSION INSULATORS.

In former practice there were comparatively few forms of insulators, but the recent development in the use of high-tension circuits has brought a great many forms into the field. The problem of adequately insulating a line with a potential difference of thousands of volts backed up by a heavy current is widely different from insulating a telegraph line.

CHAPTER XXIX.

ELECTRIC METERS.

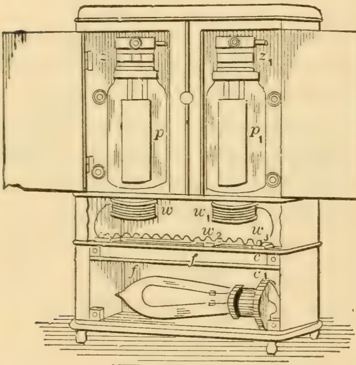
Electric Meters may measure current irrespective of voltage when they are current meters. They may measure the current and voltage when they are wattmeters.

Wattmeters operate correctly where electric power is supplied, but not for incandescent light unless a constant voltage is maintained. They only correct for about one-fifth of the deficiency in light suffered by the customer or excess obtained by him on changes in voltage. An over-compounded wattmeter would seem to be the best for light-supply metering, one which for a change of one volt would change the reading about six per cent.

Edison's Meter.—This meter was conceived on the somewhat heroic principle of the collection and weighing of metal deposited in meters by electrolytic action. The meters gave no direct reading. To get at their results, small quantities of zinc had to be weighed for each meter periodically, and the current supplied was taken as being proportional to the weight of this zinc. For years the meters in cities supplied by the Edison system were thus taken by the operative in charge. Baskets filled with electrodes were transported to the station, and the electrodes were individually weighed, and the current supplied was calculated on this electrochemical basis.

The cut, Fig. 393, shows its construction. It contained two cells, each containing a pair of amalgamated zinc electrodes. They were made of as pure zinc as possible, and before amalgamation were coated with zinc by electro-deposition. The cells contained a solution of zinc sulphate of 1.11 specific gravity. The meter had in series with the plates a coil of copper wire. The resistance of copper wire increases as the temperature rises, just

as does that of other metals. This was to compensate for the fall of resistance with rise of temperature which occurs in the solution. The meter was placed in shunt with a known resistance on the line, and its own resistance being known, it received a fraction of the total current equal to the quotient of its own resistance of the portion of the line in parallel with it divided by the resistance. The weight of zinc deposited gave the coulombs of electricity used. An incandescent lamp was automatically lighted by an expansion bar when the temperature fell, and extinguished as it rose.



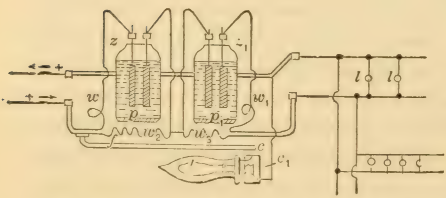


FIG. 393.—EDISON'S CHEMICAL METER—SECTIONAL DIAGRAM.

The same principle was applied to a registering meter. The plates were hung at opposite ends of a scale beam, and were alternately subjected to one or the other action, so as to move the beam from time to time. Each movement was due to a definite deposition on one plate and dissolving of the other. As the beam swung it reversed the current, and after a certain amount of coulombs had passed, it swung back. The swings were registered by clockwork or geared mechanism of the regular type.

A counter electromotive force of 0.001 to 0.003 volt caused the readings at low current to be erroneous.

Forbes Meter.—This meter was actuated by the heat produced by a current. In the lower part of a glass shade there was a flat

coil of wire which occupied a horizontal position. Above it was a vane with four inclined wings like a little screw propeller. This vane worked in very delicate bearings. The current to be measured or a known fraction of it passed through the coil and heated it. The heat caused an air current to rise from the wire, and this turned the vane windmill fashion. The turns of the vane were registered by machinery.

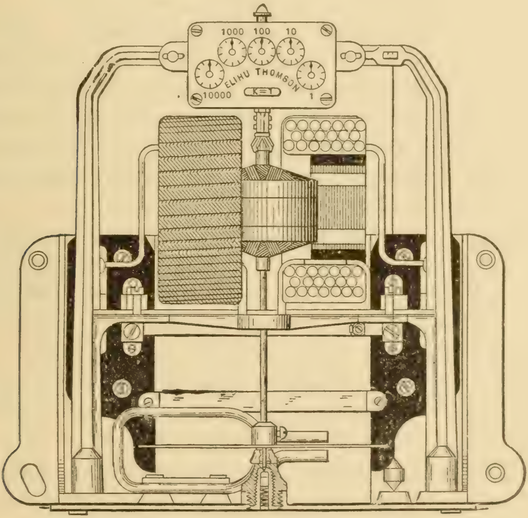


FIG. 394.—THOMSON'S INDUCTION METER.

Thomson's Meter.—This meter, due to Elihu Thomson, is a wattmeter and is shown in part section in Fig. 394. It consists of two field coils without iron core, through which the entire current which is to be measured passes. Within the coils an armature coil without iron core is mounted. It has a commutator. It receives current from the wires of the circuit, being connected across them with high resistance interposed. It receives current proportional to the voltage existing between its places of attachment. The field coils of low resistance receive all the current practically that passes. The armature rotates and drives an indicating

train of wheels like that on a gas meter. A horizontal copper disk rotates on the vertical axis which carries the armature, and steel magnets with poles brought near together embrace the outer portion of the disk between their poles, and constitute a brake on the rotation of the armature. The speed of rotation is due to the field acting on the armature. The strength of the field is due to the amperes of the current; the strength of the armature is due to the voltage of the circuit; the reading of the meter is due to the combined effect or to the volt-amperes or watts.

The meter is primarily a shunt-wound motor. An auxiliary field coil in series with the armature gives it the character to a limited extent of a compound-wound meter. This field with the armature develops alone almost enough torque to turn the armature. It therefore takes care of the friction of the meter in great part, so that the magnetic brake opposes all the resistance to its motion, a resistance increasing with the speed.

It will be seen in the cut, Fig. 394, that the permanent magnets are held in position by screws going through a horizontal bar, a portion of the frame of the meter. These can be loosened if desired, and the magnets can thus be moved in and out. This operates to regulate the meter and make it move faster or slower. It can thus be tested with lamps, and adjusted over a range of about 16 per cent. An alternating or direct current can be measured by this meter.

For three-wire systems, one of the field coils takes the current of one active wire; the other coil that of the other active wire. The coil in circuit with the armature is connected across from the neutral wire to one of the outer wires, thus getting the voltage of one lamp, or customer's voltage. Sometimes the shunt field coil and armature are connected across the outer wires, thus taking twice the voltage. A transformer can be used in alternating current supply where the voltage is too high for the resistance of the meter. In meters for heavy currents a single copper bar passing between two armature coils constitutes the field.

For two and three-phase alternating-current circuits a combination of two or three meters in one is made. One dial gives the reading. Otherwise, two meters can be connected to give the readings of three-phase systems. The sum of their readings is

taken. If the lag exceeds 60°, giving a power factor of less than one-half (cos $60° = \frac{1}{2}$) one of the wattmeters will have a negative reading, in which case it must be subtracted from the reading of the other one.

For series systems the field is in series with one of the main conductors, so that the full current, which is not a very high one, goes through it. The meter gives watt hours.

Shallenberger's Meter.—The entire current passes through a fixed coil of few turns. Within this coil is a second one with self-contained re-entrant circuit, constituting an induction motor armature, as it has no outside connection. Its axis is at an angle with that of the outer coil. When an alternating current passes through the outer coil, it induces a current in the closed circuit of the inner coil. A reaction is established with a resultant field between the two fields, one of the outer and the other of the inner coil, which fields are not coincident in position, but lie at an angle to each other, equal to the angle between the axes of the coils. There is also a difference of phase between the two coils, which causes the resultant of the fields to rotate, thus constituting a rotary field. A vertical arbor or spindle carries a horizontal metallic disk which lies in the field, and is acted on by the rotary field when current passes, and caused to rotate. To retard its motion, air vanes are carried by the spindle. The principle of the meter is that the torque increases with the square of the current, being due to the energy expended. The resistance offered by the vanes varies with the square of the speed. Thus, the speed of rotation of the disk is directly proportional to the current strength. This meter is a current measurer, taking no direct cognizance of the volts of the circuit.

CHAPTER XXX.

LIGHTNING ARRESTERS.

Lightning Protectors.—Atmospheric electricity produces disturbances in electric apparatus unless means are taken to give it a way of escaping to the ground. Whatever the nature of the disturbance, so great a voltage is established that the current due to the atmospheric electricity can jump across an air gap quite impassable for working electrical currents.

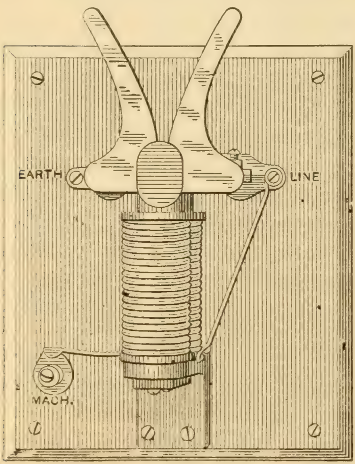


FIG. 395.—MAGNETIC BLOW-OUT LIGHTNING ARRESTER.

Comb or Saw-Tooth Arrester.—This was one of the early protectors. Attached to the line to be protected was a plate with a series of saw teeth on one edge. The plate might be an inch long. A similar plate faced it tooth to tooth, both being screwed flat on a board. The second plate was connected by a conductor to the earth. Ordinarily the working electrical apparatus would contain electro-magnets or similar appliance of high inductance. If a disturbance occurred, producing a discharge on the line, the regular apparatus by its inductance would choke back the discharge, which would jump across the gap from one set of teeth to the other, and so escape to the earth.

Magnetic Blow-Out Arrester.—This is shown in Fig. 395. The

two flaring plates of metal approach each other closely at the lower end. One is connected to the earth, the other to the line. An electro-magnet is in the line circuit. Lightning on the line is choked back by the magnet, owing to its inductance springs across the gap, and goes to the earth. Any arc which it may form is blown out by the magnet. It is driven toward the diverging ends of the plates, and breaks. The three connections to line, earth and machine are indicated in the cut.

Non-Arcing Metal Arrester.—This arrester is made up of a number of cylinders of metal of the cadmium group or near it, which does not readily maintain an arc if in the position of electrodes. Fig. 396 shows the construction. The seven cylinders have about one-thirty-second inch of air between each two. The exterior or end cylinders are connected with the line, and the central cylinder is grounded. The other four serve to form the additional gaps. With alternating currents this arrester forms no arc after a discharge; with direct current it may form a harmless one.

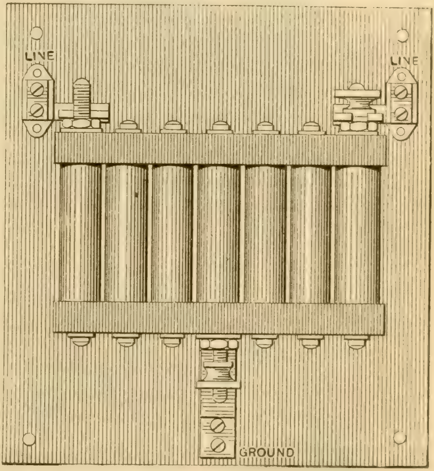
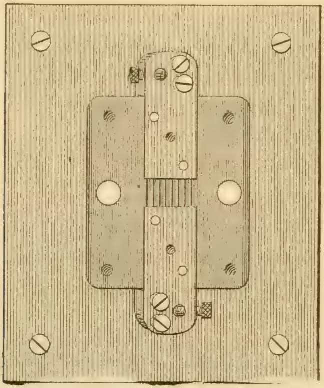
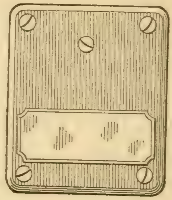


FIG. 396.—NON-ARCING METAL LIGHTNING ARRESTER.

Discriminating Arresters.—This name is due to Mr. A. J. Wurtz, the inventor of the last described as well as of this arrester. Two brass terminals an inch wide are laid in grooves and flush with the surface of a block of marble. Their ends come within half an inch of each other. A piece of lignum vitæ fills the gap between their ends and across it are made a series of charred grooves about one-tenth of an inch wide and one-thirty-second of an inch deep. A cover of marble is secured over it.

One plate is grounded; the other is connected to the line. No ordinary current can pass over the charred surface, which acts to





FIGS. 397 AND 398.—WURTZ'S CARBON LIGHTNING ARRESTER.

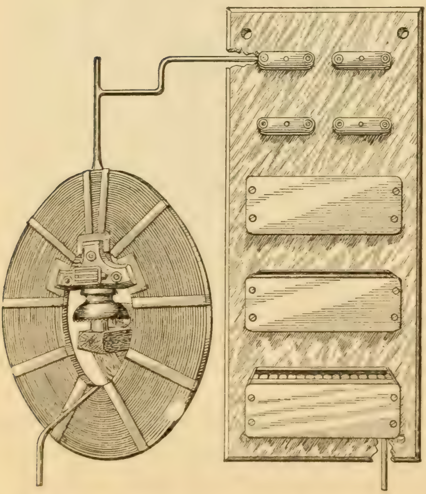


FIG. 399.—WESTINGHOUSE LIGHTNING ARRESTER.

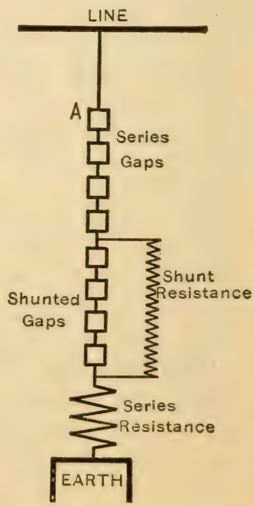
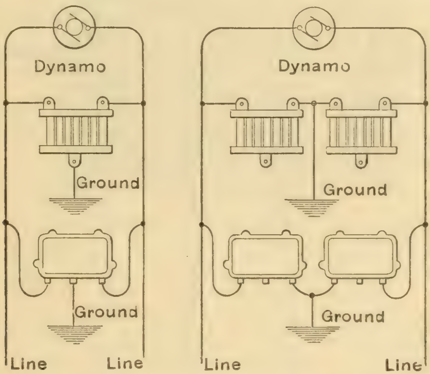


FIG. 400.—ALTERNATING CURRENT LIGHTNING ARRESTER.

conduct the atmospheric discharge to the earth. No arc forms in this apparatus. The resistance of the apparatus may be as high as 50,000 ohms. Sometimes no marble is used, the electrodes being screwed directly to the wooden block of lignum vitæ. It is shown in Figs. 397 and 398.

Westinghouse Lightning Arrester.—A disk-shaped choke coil is carried on an insulator, as shown in Fig. 399. This coil has sufficient inductance to oppose the passage of a lightning discharge, yet not enough to seriously affect the current. To the



FIGS. 400*a* AND 400*b*.—DOUBLE-POLE LIGHTNING ARRESTERS.

right are non-arcing spark gaps. The line is connected above and below the coil; the lateral connection gives the path for the lightning discharge, which goes to the earth through the arresters, which are of one of the types already described.

Low-Equivalent Alternating-Current Lightning Arrester.—In Fig. 400 is given a diagram of an alternating-current lightning arrester for high-voltage currents. Its action is as follows: The discharge springs across the gaps and goes to the earth. Any arc formed in the shunted gaps is destroyed by the path for the current offered by the shunt resistance. The series resistance is made as non-inductive as possible, and acts to reduce any current which follows the discharge. A certain amount of the discharge goes through the shunt resistance.

Double-Pole Lightning Arrester.—The diagrams, Figs. 400 *a* and *b*, illustrate double-pole connection of lightning arresters, where they are connected like lamps across the two leads of a circuit.

Tank Lightning Arrester.—This arrester is found particularly serviceable on electric railways. Choke coils carried on a slate or marble base are put in the circuit, as shown in the upper part

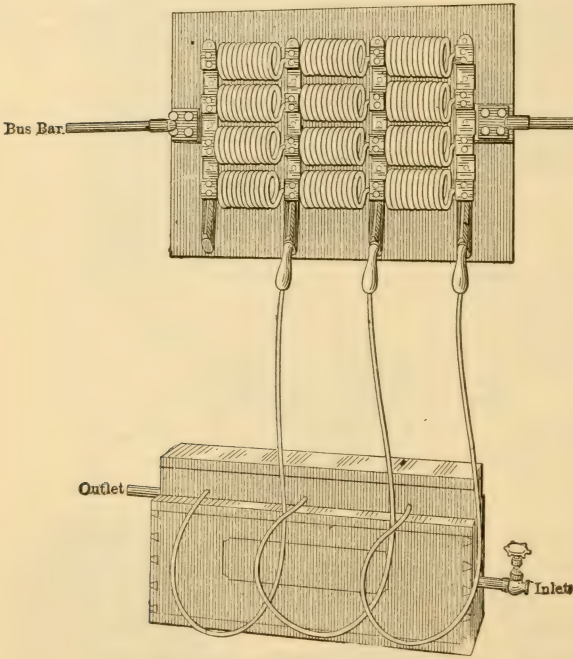


FIG. 401.—TANK LIGHTNING ARRESTER.

of Fig. 401. Conductors from the coils run down to a tank of water shown in the lower part of the cut. Water is run through the tank when a storm threatens. A slight current leakage constantly takes place, but is trifling. If a lightning discharge occurs, it goes to the earth by way of the tank. The choke coils force it to the tank.

CHAPTER XXXI.

THE INCANDESCENT LAMP.

Incandescent Lighting.—The incandescent lamp is the expression of a fundamental law of electric supply, which is to the effect that resistance in an electric circuit should be concentrated at the point where energy is to be developed. If a circuit is devoted to running machinery, the resistance should be in the machines, and as little resistance as possible should be in the lines. If lamps are to be lighted, as much of the total resistance as possible should be concentrated in them.

In the case of incandescent lighting, the useful resistance is that which is produced by the filaments of the lamps. All resistance not manifesting itself through heating the thin filaments represents lost power and waste of energy. It is a curious thing that the useful energy of every horse-power in an incandescent electric-light system is represented by the ignition of only five or six feet of carbon filament.

The Incandescent Lamp comprises a filament of carbon of various shapes, approximating to a letter U. The filament is inclosed in a glass bulb within which a vacuum is produced. Wires passing through the glass are connected to the source of current, which heats the filament bright red or white hot, so that it emits light.

Tamidine Filaments.—Weston made for the basis of filaments a substance which was named tamidine. It was prepared from solid massive nitro-cellulose, the substance left by the evaporation of collodion, so familiar to the old-time photographer, and now used for surgical treatment of minor cuts and the like. The nitro-cellulose was reduced by a chemical reducing agent such as sulphureted hydrogen, converting the mass completely or nearly into cellulose. This material resembled transparent

horn. Filaments were cut out of it, were carbonized, and used in lamps.

Squirted Filaments.—Filaments are now made also by forcing the proper material through a die. A thick solution of nitro-cellulose, which is a syrupy collodion, can be forced through a fine aperture and evaporated, giving a thread. This after reduction could be used as a basis for filaments. Cotton can be dissolved in a solution of zinc chloride, giving a syrupy transparent solution. This can be forced through an aperture into a vessel of alcohol. This hardens the thread so that it can be handled. The zinc chloride is washed out of it as far as practicable, and it is eventually wound on drums as a long thread, resembling the fisherman's silkworm "gut," which is attached to the fishhook.

The thread made as described is cut into the proper lengths ready for carbonization. Various practical details have to be followed. Bubbles are one of the troubles. The thick solution retains these with some persistence, and heating the solution in a vacuum is sometimes used to expel them from the solution. Perfect evenness of the solution is secured by thorough stirring, and an exact formula for the solution is followed. The purified cotton prepared for physician's use under the name of absorbent cotton is the best material for the process. Filaments made by this method are called "squirted filaments."

Carbonization is effected by heating the thread to redness in an oven. It is protected from the air by being imbedded in powdered charcoal, or by some method by which no oxygen can reach it while heated. It would instantly burn if air had access to it while at a red heat.

Calibration. — As the process is usually carried out, the thread from the circular die is still somewhat soft when wound off upon the drum, and the winding flattens it a little. It is necessary to have filaments of exact dimensions, so the filament of oval section is calibrated in two directions to determine its cross-sectional area after carbonization. Filaments are thus sorted out for various resistances. The length is not so conveniently changed, as the bulb is supposed to be suited for a certain sized loop of filament.

Flashing.—The filaments from the carbonizing oven are next

flashed. This process was a very early conception. The electric-light filament is increased in density, elasticity, and hardness by it, its pores being filled and its surface being coated with graphitic carbon. A number of the filaments are fastened by holders of metal to the stopper of a jar. This jar is filled with vapor of naphtha or other hydrocarbon, and the stopper is inserted with the filaments on its inner side protruding into the jar. A current is passed through them, igniting them to bright redness. The thin parts get hotter than the thick ones. The hydrocarbon is decomposed when it comes in contact with the hot filament, and more of it is deposited where the filament is hottest, which is where it is thinnest. Thus flashing not only solidifies the filament, but builds up its thin places.

Occlusion of Gases by Filament.—A porous solid has sometimes a peculiar action on gases which is termed occlusion. Gases will thus be retained much as water is retained by a sponge. The thread of cellulose or cotton before carbonization is as absolutely without pores as anything can well be, but in the carbonization process it becomes full of pores, and these may occlude oxygen. When such a filament is placed in an exhausted bulb, all of the gases may not be given up until ignition is applied by the current. If gas is thus introduced into the bulb, it will have a bad effect upon the filaments. The flashing process fills the pores, and gets rid of occluded oxygen by combustion as well as ignition.

Lowering of Resistance by Flashing.—The flashing process lowers resistance 10 to 15 per cent, so due cognizance must be taken of this action in selecting the size of filament for any given lamp. It is easy to bring about any desired resistance by flashing, and the resistance can be determined if desired from time to time during the process. The logical way of determining resistance is to do it while hot, as the resistance of a lamp when cold is only an indirect factor as far as its use is concerned.

Making Joints by Flashing.—The filament has to be fastened to a wire at each of its ends, and an interesting application of flashing is the making of a joint between these wires and the filament. It is made by flashing the filament in a hydrocarbon vapor or even in liquid naphtha through the wires held against the ends of the filament. A solid coating of hard graphite is

thus formed around wire and filament end, just as if a soldered joint were made.

Pasted Joints.—An easier and cheaper way to make the joint is to put a little putty-like mixture of finely-powdered carbon and molasses around the junction of filament and wires. On ignition this hardens and forms a secure joint.

Electroplated and Other Joints.—These are made by electrolytic soldering. A coating of copper is deposited over the junctions of wires and filaments by electroplating, forming a conducting coating over wire and filament ends. The joint has often been made by a very small bolt, which passes through holes in the enlarged ends of the filament and wire, and has a nut screwed on its end. Another system is to have sockets in the ends of the wires, into which the filament ends are thrust. The flash joint and carbon paste joint are the principal ones used in recent practice.

Leading-in Wires.—The solution of the problem of passing a wire through glass and then melting the glass around it so as to form an air-tight joint hinges on the coefficients of expansion by heat of the metal and glass. These must be practically the same, or else the wire will work loose from the glass, forming cracks, perhaps very minute yet sufficient to admit air. All sorts of combinations of different kinds of glass and metals have been tried. The practice has now settled down into the use of platinum leading-in wires, which are passed through holes in the glass. The glass is then melted around the wires. The metal platinum expands and contracts under changes of temperature almost exactly as much as glass. It possesses another property of considerable importance, which is that it is inalterable under any ordinary range of temperature. It will not oxidize at any temperature, and melts only at very high heats, far higher than any to which it is exposed in the construction or operation of the incandescent lamp. This use of platinum has drawn very largely upon the supply, and its tendency is to rise in price. The lamp maker uses as little as possible, electrically welding copper wire to the platinum, so as only to use enough of the rarer metal to pass through the glass.

Making the Lamps.—The methods differing in details, the fol-

lowing cut, Fig. 402, gives a typical process. No. 1 shows a glass tube closed at the upper end, with the leading-in wires passing through it, melted in, and with the carbon filament attached. No. 2 shows the globe with long exhaust tube with the filament thrust into it. No. 3 shows the melting together of the two pieces of glass with a blow-pipe flame. No. 4 shows the lamp with filament tube melted in ready for exhaustion, and No. 5 shows the lamp after exhaustion with its exhaust tube melted off, the lamp being ready for use.

Vacuum.—The bulb of an incandescent lamp after the carbon

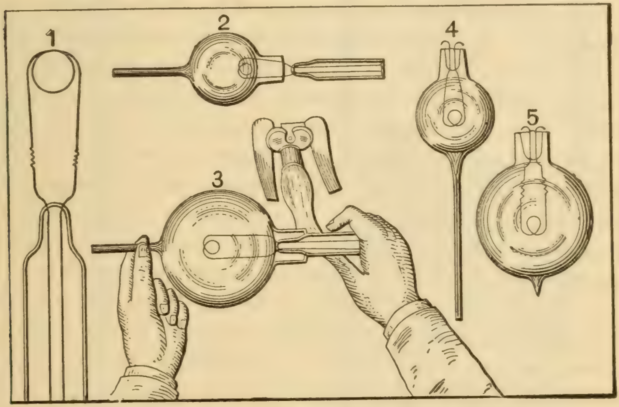


FIG. 402.—MAKING INCANDESCENT LAMPS.

is in place is exhausted until a very high vacuum is produced in it. The vacuum was originally designed to prevent the carbon from burning, but it accomplishes other results also. It keeps the filament hotter. If the bulb is filled with an inert gas, the gas under the effect of the hot filament enters into active circulation, cools itself against the sides of the bulb, gets heated by the hot filament, and then is cooled again. The filament has to heat the gas over and over again, and the temperature is materially lowered by the process. The efficiency is thus diminished.

An exhausted bulb is much cooler when the filament is giving light than if it were filled with inert gas. As a mere matter of

convenience this is desirable. It is a good feature about the incandescent lamp that its bulb cannot burn the hand, or set fire to anything under normal conditions, although it is not altogether safe to leave burning lamps wrapped up in a combustible wrapping for a considerable period.

Production of Vacuum.—The Torricellian vacuum, Fig. 403, such as exists above the mercury in a barometer tube, is one of the best vacuums produced without special care or for special ends. The Sprengel and the Geissler pumps are based upon the production of this vacuum. In these air pumps the piston is represented by a column of mercury, and the force driving the piston is represented by the pressure of a column of mercury over 30 inches high. A quantity of the lamps are sometimes exhausted to a pretty high vacuum by a mechanical air pump, and the exhaustion is finished by the use of a mercurial pump. This removes the last air, whose removal is facilitated by passing a current of electricity through the filament, heating it as the close of the operation is reached. This expels any occluded and other gas held by the wires, glass or filament. Sometimes a little phosphorus is put into the exhausting tube and is heated from the outside by applying a flame or other source of heat to the glass on which the phosphorus is lying. It combines with any trace of oxygen present. To prevent danger to the health of the operatives, and to avoid liability of ignition of the phosphorus, the modification called red phosphorus is best for this purpose.

External heat can be applied to the lamp during the last of the exhaustion to assist the operation. The exhaustion is done through a tube extending from the top of the bulb. This tube is melted off in the blowpipe flame when the exhaustion is complete. The point seen on the end of the bulb shows where the sealing was effected.

The Mercury Air Pump.—The Sprengel pump utilizing the Torricellian vacuum is shown in Fig. 404. At the top of the pump is a horizontal pipe, through which mercury is passed. At D D are cocks admitting it to the pumps, one of which is shown on the left. The mercury descends through B, goes through the inclined tube down T and out through D′ D′, to be repumped into the upper pipe. R is a glass vessel containing a

drying agent, such as phosphoric oxide or sulphuric acid. At O is an opening into which the exhausting tube *a* on the upper end of the lamp L can be sealed. It has another opening at S communicating with T. The mercury as it leaves the inclined tube, if there is a trace of air in R, breaks up into little columns

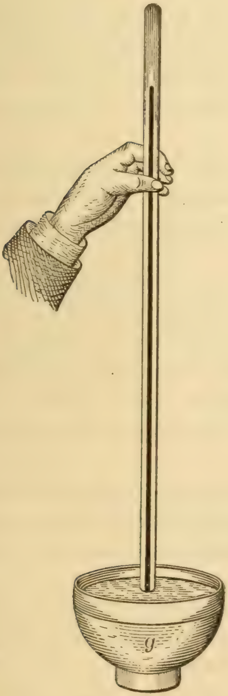


FIG. 403.—TORRICELLIAN VACUUM.

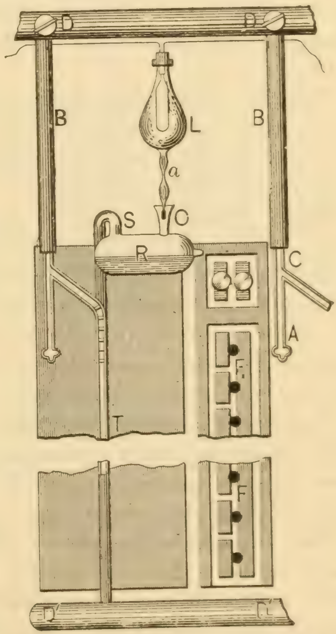


FIG. 404.—SPRENGEL'S AIR PUMP.

and draws the air down and out. The filament is heated during the process by a current adjusted in intensity by the resistance coils F F.

In modern works various kinds of special pumps are employed to work on the large scale, exhausting a number of lamps simultaneously.

The Geissler air pump is operated by the agency of a column of mercury, but involves the raising and lowering of a reservoir of mercury. The Sprengel pump is described as a typical mercurial air pump.

Luminescence is the quality of giving light when heated. All substances possess more or less of this quality, some in higher degree than others. Luminescence of a very high degree is shown by the Welsbach incandescent gas light. A filament of its material would represent an almost ideal substance for an incandescent lamp filament if it was heated so as to become a conductor.

Metallic Filaments have been tried for incandescent electric lamps with very little success. Their fusibility is the principal objection to their use. At present the metals osmium and one or two others are being tried.

Oxide Filament.—There are substances which are free from most of the objections which attach to carbon and the metals, except that they normally do not conduct electricity. These are the oxides of the metals of the earths, lime, magnesia, and others. They are in the full sense non-conductors when cold, having enormously high specific resistance, but on heating they become conductors.

The Nernst Lamp is an incandescent lamp whose filament is made of earth oxides. These are absolutely incombustible, so that they can be ignited in the air, providing the condition for an open-air incandescent burner.

The Glower.—The Nernst lamp filament is a straight bar of earth oxides and is termed the glower. To its ends are attached wires. The current once made to pass through the glower raises it to a white heat, produces light, and keeps it in the conducting state. The composition of the glower is not disclosed. It is said to be composed of the rarer earths, resembling the Welsbach gas mantle in composition. The standard glower for 220 volts is almost exactly an inch in length and 0.025 inch in diameter. It is formed from a putty- or dough-like mixture of the earths, by squeezing them through an aperture in a die. This produces a thread, which is dried and baked. The cuts of the Nernst lamp all show the glowers.

Glower Terminals.—The connection of the wires with the glower was originally effected by winding platinum wire around the ends, and puttying over the ends with cement. This did not work very well, as the wires were apt to become partly detached, and thus had their contact with the glower made imperfect. The result of this was that the glower soon broke near the terminal, where the bad junction caused a concentration of heat. Another method is based on the reverse principle. A globule of platinum at the end of each wire is embedded in each end of the glower. Any shrinkage in the material of the glower causes it to grip the bead still tighter. It cannot shrink away from it, as it tends to shrink from the wires wound around its exterior. Conducting wires fused to the platinum globules project an inch or two from the ends of the glower. The ends of the conducting wires are fastened to the body of the lamp by little aluminium plugs.

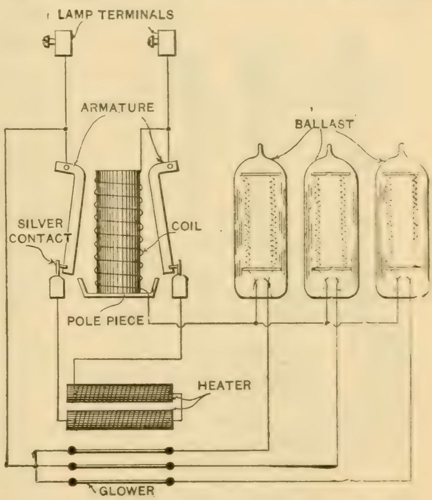


FIG. 405.—DIAGRAM OF NERNST LAMP CONSTRUCTION.

The ends of the wires are thrust into holes in the two contact blocks of the lamp, and the plugs are forced into holes, wedging them fast.

The glower becomes a conductor when heated to about 1300° F. (700° C.). When cold it is a non-conductor.

Heaters.—The glower can be heated by a match or alcohol flame, in order to make it conduct current. In the lamp as now made electric heaters are used, also shown in the cuts. These are of various shapes, consisting of platinum wire wound upon a porcelain form and imbedded in refractory paste. When the

lamp current is turned on, none can go through the cold glower, and a slight current only passes through the heater. It is enough to make it quite hot; and as it is in close proximity to the glower, it heats the latter, which in a few seconds begins to pass a current strong enough to excite a magnet, which attracts pivoted armatures cutting out the heater, and thereafter all the current goes through the glower or glowers. The heater has to heat the glower up to a temperature of about 1742° F. (950° C.)

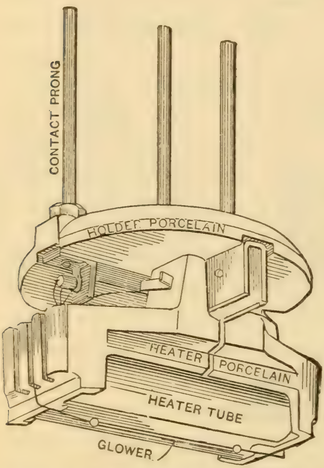


FIG. 406.—NERNST LAMP READY FOR INSERTION IN ITS SOCKET.

Ballast.—The glower is in series with a steadying resistance, which is called the ballast. The resistance of the glower diminishes with increase of temperature. The resistance of iron wire increases with increase of temperature, and the two balance each other approximately, which prevents the glower burning out. The case is analogous to the use of the individual resistance in a constant-potential arc lamp. The Nernst lamp has to be employed on fixed-potential circuits. Iron wire is selected for the ballast because it possesses in a high degree the property of increasing in resistance with increase of temperature. It is inclosed in glass tubes hermetically sealed and filled with nitrogen gas, and is shown in Fig. 405.

The Cut-Out, also shown in Fig. 405, is an electro-magnetic switch which opens a circuit when its magnet is excited. This circuit is normally closed, and only opens by the action of the electro-magnet as described above. The magnet winding is in series with the glower; the circuit which it opens contains the heater.

Direct-Current Lamps.—If used on direct current, a blackening of the glower near the negative end takes place, which causes

the efficiency and candle power of the glower to fall off. Its durability is also impaired. On alternating current this action does not take place, and its life is much longer.

Vacuum Lamps —If the glower is inclosed in a vacuum, its efficiency as far as the glower is concerned is increased. But this increase is accompanied by a very rapid rate of diminution of resistance with increase of temperature. This has to be met by a larger ballast, which reduces the efficiency. It is considered preferable to inclose it in a globe with access of air. This gives

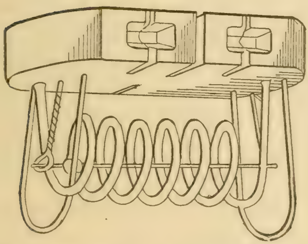


FIG. 407.—SPIRAL HEATER AND SINGLE HORIZONTAL GLOWER OF NERNST LAMP.

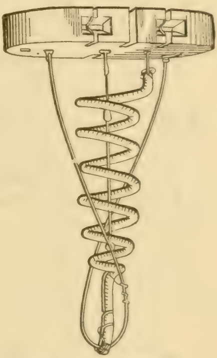


FIG. 408.—SPIRAL HEATER AND SINGLE VERTICAL GLOWER OF NERNST LAMP.

enough cooling to lighten the work of the ballast, and yet to give higher efficiency than in the open air. Before a glower breaks, the voltage rises rapidly until the rupture occurs and the lamp goes out. Sometimes as many as six glowers are put into one lamp, in which they are simultaneously ignited. The efficiency of such is higher than that of a single-glower lamp.

The Efficiency of the Nernst Lamp is about double that of the ordinary incandescent lamp.

The cuts, in the light of what has been said, are self-explanatory. Fig. 405 shows the parts of a lamp in diagram. The magnet coil being inactive, the pivoted armatures are not yet attracted. When attracted they open the circuit at their lower

ends, one of which is marked "silver contact" in the diagram. Fig. 406 shows the heaters and glowers of a lamp ready for insertion into the socket, the parts being marked. The next cuts, Figs. 407 and 408, show spiral heaters surrounding the glowers.

Distribution of Light.—The diagram, Fig. 409, shows the

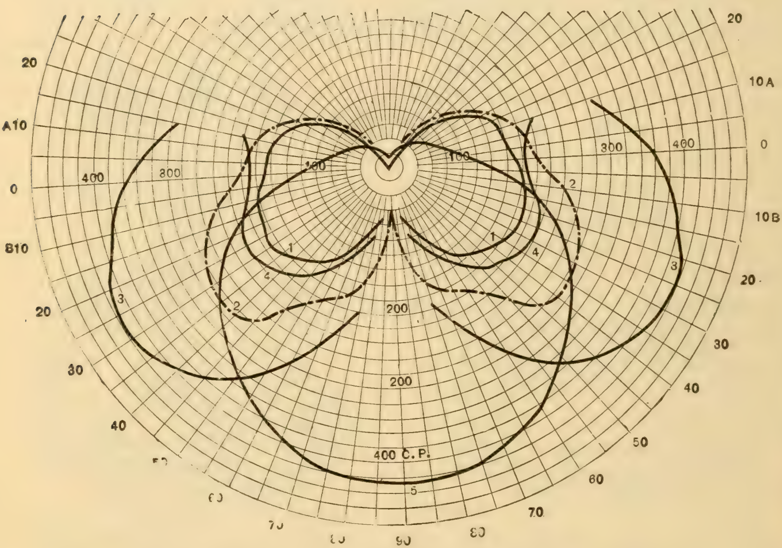


FIG. 409.—DISTRIBUTION OF LIGHT FROM THE NERNST LAMP.

distribution of light of a Nernst lamp and of other lamps in the vertical plane as by the following table:

1. 110-volt, A. C. constant potential arc, 6.3 amp.
2. 110-volt, D. C. constant potential arc, 4.9 amp.
3. 6.6 amp. D. C. series arc, 71.6 volts.
4. 6.6 amp. A. C. series arc, 65.4 volts.
5. 6 glower Nernst lamp, 220 volts.

Arc lamps—Opalescent inner and clear outer globe.

Nernst lamp—8-inch sand-blasted globe.

CHAPTER XXXII.

THE ARC LAMP.

The Voltaic Arc.—If two rods of carbon are connected to a source of current and are brought into contact with each other, and are then separated a fraction of an inch, the current will continue to pass across the interval. An intense heat is produced, and the space between is filled with carbon vapor and minute particles. The heat makes the carbons very hot. As carbon is not a very good conductor of heat, almost all the heat concentrates on the ends. The arc may be produced by direct current or alternating current, which gives two divisions of the subject, direct-current and alternating current arc.

Positive and Negative Carbon.—When a direct-curent arc is produced in the open air between two carbon pencils, both wear away, but do so differently. One keeps a pointed end, like a sharpened lead pencil, and is the negative carbon. The other has a little crater or cup formed on its end, and is the positive carbon. The latter gives far more light than the other. Naturally, the interior of the crater radiates the most light. In direct-current arcs the crater of the positive carbon is made to face as nearly as possible in the direction in which the light is to be utilized. Thus, for overhead lamps the positive carbon is placed uppermost, so that its crater radiates light to the ground.

Striking the Arc.—The arc will not strike across a space filled with air unless a very short one. The carbons may be arranged to stay in contact when idle and to be pulled apart the instant the current starts. As they separate, the arc forms across the gap or space between the ends of the carbon rods. This is the universal way of operating arc lamps, although it can be done otherwise. If a spark can be made to strike across the gap, the arc will start over the path thus made for it. The air between

the poles is intensely heated, and is a tolerably good conductor, so that once the arc is established, it can be drawn out to a considerable length—greater than the striking distance of the potential utilized.

Heat of the Arc.—The resistance of the arc is not great enough to account for its intense heat. The positive pole is hotter, 7200° F. (4000° C.) than the negative, 5400° F. (3000° C.) to 6300° F. (3500° C.). Counter electromotive force is set up, due to thermo-electric effect, or to condensation of carbon vapor, and is equivalent to resistance, and the heating effect results. The higher temperature of the positive pole causes it to wear away the faster. With alternating currents the poles wear evenly, and with almost flat ends if the arcs are inclosed in a glass globe so as to be partly protected from the air.

Voltage Drop.—In a direct-current arc the voltage drop between the positive carbon and the arc has been determined to be about 40 volts. In the arc itself a drop of 2½ volts was observed, and a 2½-volt drop between the arc and the negative carbon. These determinations are not to be considered accurate. They indicate the distribution of voltage, of resistance, and of light-giving areas or volumes with a good degree of approximation.

Counter Electromotive Force is believed to exist in the direct-current electric arc, and to account for part of its apparent resistance. The cause is not certain. The different temperatures of the carbons producing a thermo-electric effect has been assigned as its cause. The alternating current arc, both of whose carbons are of identical temperature, exhibits apparent resistance enough to have counter electromotive force attributed to it. Solidification of carbon vapor may be the cause of its production in both direct and alternating current arcs. It would be possible to imagine the rapid volatilization and condensation of carbon vapor in the successive cycles of an alternating current as producing an alternating counter electromotive force.

The counter electromotive force for a 10-ampere 45-volt arc with pure carbons has been put at 35 to 39½ volts. This is approximate only. All determinations affecting the internal physics of the arc must from the nature of things be difficult to execute, and the results will generally be approximate.

The Resistance of the Arc Proper has been placed at about 5 ohms per inch of length. The 10-ampere arc, which is a standard, varies from 1/10 to ½ ohm in resistance, the arc length varying from 1/16 to ⅛ inch. Questions in which length of arc is involved are only to be valued approximately, as there is nothing accurate about the determination of its length.

The resistance of the arc varies inversely in some ratio with the current. A heavy current diminishes the arc's resistance. This is the reason an arc lamp without a resistance or inductance for alternating currents cannot be used on parallel or constant potential systems. This diminishing of resistance is partly due to reduction of the resistance of air by heat, for the more intense current heats the air to a higher degree and heats more of it than does the smaller current. Another cause is the presence of carbon in the arc, probably as vapor, possibly as particles, which is increased in relative amount by greater heating. The old modification, which has recently been experimented with, of introducing alkaline earth salts or the like into the arc diminishes its resistance by supplying it with vapor of these salts or of their constituents. Increase of pressure increases the resistance. This applies to pure carbon arcs, and is by some thought to produce this effect by preventing the production of the full amount of carbon vapor.

Efficiency of the Arc Light.—Of the efficiency of the arc as a light producer nothing can well be said beyond the comparison with other sources of light. The two reasons are that the arc is very seldom photometered, and that the absolute unit of light is as yet undetermined. If light is defined as that which affects the retina of the eye, its mechanical equivalent may be exceedingly small. What we know about odor tends to ratify this belief. An almost inconceivably small quantity of matter is required to affect the olfactory nerves. A very minute amount of energy is represented in the action of light upon the optic nerves.

The arc is one of the most efficient sources of artificial light. The magnesium light is put next to and very close to it, and by modifications might be made to equal or exceed it. It is 8.66 times as efficient as candle light, 13 times as efficient as gas light,

5.2 times as efficient as the Welsbach light. These all are so variable that the relative figures given are only approximations.

The reason of its efficiency is that its heat is so intense. There is a possibility that there is a considerable loss by some of the heat producing ether waves of so short a period that they do not affect the optic nerve or are not visual.

Quality of Carbons.—The nature of the carbons affects the efficiency. The great agent of economy is the concentration of heat at the ends of the carbon. Too hard a carbon is apt to be a relatively good conductor of heat and therefore uneconomical. A small diameter of the carbon pencil favors concentration of the heat at the point, and small carbons give higher results. The efficiency diminishes approximately in inverse ratio with the diameter of the carbon. A soft core in the carbons reduces the efficiency. In order to give better surface contact between the carbon clamps and the carbons, the carbon pencils are often copper-plated, and nickel plating has been applied. This diminishes the light a little by improving the conductivity of the carbons for heat.

Power Consumed in Arc.—A consumption of 480 watts is usual in a nominal 2000-candle-power lamp. The ratio of volts to amperes in the production of the watts expended in an arc lamp affects its efficiency and consequently its light. Carhart found that 45 volts and 10 amperes gave a maximum light of 450 candles or 1 candle to the watt. With 8.4 amperes and 54 volts the maximum candle-power was doubled. There is nothing definite about these figures, as the size and quality of the carbons would affect them materially.

Effect of Air Blast.—A blast of air will blow out an arc as it will a candle flame. This principle is utilized in the Thomson-Houston alternating-current dynamo. A blast of air is there produced by a rotary blower, which is directed on the ends of the brushes to blow out any arc which may form in the operation of the machine.

Effect of Magnet.—A powerful magnet deflects the arc to one side, and if near enough thereto and strong enough, will blow it out as a blast of air will.

Voltage Drop and Arc Length.—Where the arc produced be-

tween two carbons attains a certain length, it has to be increased in length to keep a fixed voltage. This is in line with the properties of the arc, which makes it impossible to operate arc lamps on constant-potential circuits without auxiliary resistance coils. The resistance falls with increase of current, and the lengthening of the arc is necessary to bring its voltage back to its original figure.

Wearing of Carbons.—With a direct current the positive carbon wears away about twice as fast as the negative. The latter has a little accretion of carbon particles form upon it, which may increase its length. This amounts to nothing from the practical standpoint. In open arc practice, when the arc is produced in the open air, the accretion burns away.

With an alternating current the wearing of the carbons, other things being equal, is the same for both. But when they are placed vertically, as they always are now, the upper carbon has been found to wear away about eight per cent faster than the lower one. This is due to the uprising currents of air and to gravity acting on the transfer back and forth of carbon particles.

This uneven wearing away of the carbons affects the operation of arc lamps for some special purposes. Such occur in its use in searchlights and lighthouses, where the center of light must be at the level of the focus of the lens or reflector. Different feeding rates for the two carbons may be used to keep the light-giving gap in its proper place.

Arc Light Carbons.—Carbons are made from a mixture of finely ground and ignited carbon with some carbonaceous cementing material such as pitch. They are molded into shape and baked for a long period at a red heat with exclusion of air. Two general systems of molding them are followed.

In one grooved plates are the molds. The plates contain straight grooves of semi-circular section spaced equally on both plates, so that when the plates are laid face to face the grooves form a series of cylindrical molds. The composition is molded in these. Carbons which have been made by this or analogous methods sometimes show on their peripheries the mold print.

The filled molds are heated in an oven until the mixture softens, when they are subjected to a hydraulic pressure of several hun-

dred tons. They are then removed, and any fin left where the joints between the molds come is scraped off, and they are ready for baking.

In another system the carbon composition is forced through a die by a hydraulic or other form of powerful press. The die which is at the foot of the apparatus has a circular aperture of the size of the carbon. The cylinder is filled with composition which is forced out through the aperture or die. As the cylinder emerges it is cut into the correct lengths and the green carbons are baked.

In modern practice the mixture is made into cylinders fitting the press cylinder. The size may be about six inches long and two to six inches in diameter. The cylinders are horizontal.

To produce cored carbons a circular mandrel extends through the aperture of the die, and the carbon is forced out in the shape of a hollow cylinder. The central opening of the carbons is then filled with a composition, which on baking gives a softer carbon. The object of the cored carbon is to hold the arc in inclosed lamps in a central position.

The baking of carbons has to be sufficient in temperature and duration to completely decompose the cementing pitch or syrup, and to give them good conductivity. Too much baking may make them too hard. Too rapid application of heat may warp them, and it is essential to good operation that they should be perfectly straight. To keep them straight during the baking and to exclude air, one method adopted is the imbedding the green carbons in sand, one layer of carbons above the other in the furnace. From seven to fourteen days may be consumed in charging a furnace, baking the carbons and cooling.

The crooked carbons are sorted out from the lot by rolling on a plane surface. If not too crooked, the ones thrown out by the rolling test are sold as seconds. From crooked carbons, short ones useful as bottom carbons can sometimes be cut.

The forced carbon, as the one made by the die process is called, is used in inclosed arc lamps, especially in carbon feed lamps.

The Direct-Current Open Arc is the arc produced by direct current between two carbons in the open air. It varies in current from 6 to 10 amperes, and in electromotive force expended or

drop from 42 to 52 volts. This refers to ordinary or standard size lamps, such as are in general use. Larger lamps with carbons of greater diameter use more current. Some very large lamps have used carbons of an inch or more in diameter.

A very large number of open-arc lamps are still in use. The new installations are almost universally fitted with inclosed-arc lamps. One of the great expenses of conducting an open-arc light system is the frequent trimming of the lamps. This requires time, which involves a labor charge. The carbons require frequent replacing as they burn out, which is another item of expense.

Distribution of Light in Direct-Current Open Arc.—The gas engineer has always tested the light given by a gas flame in the horizontal direction. It has never been the practice to try it at various angles from the horizontal. With gas this would be far from easy, because the gas flame must burn vertically, and the construction of a photometer to test its value as a light giver at different angles would be somewhat difficult. The electric light, arc as well as incandescent, is far from being as sensitive to change of position as is the gas flame, and by inclining the lamp in different positions, candle-power at various angles is determined. This is spoken of more at length elsewhere.

With an arc lamp with carbons end on to each other, now the invariable position, the following variations of candle-power to angle exist with direct current.

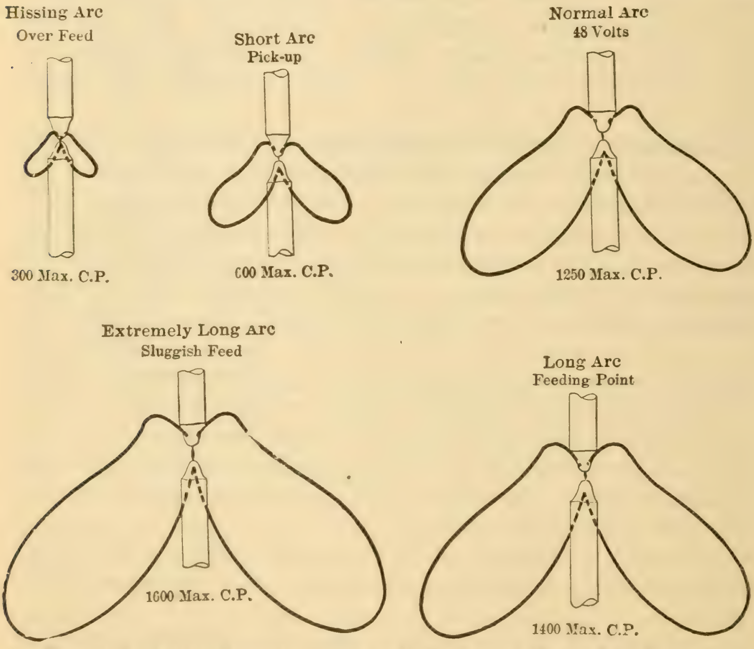
The horizontal direction gives a low candle-power. The crater is screened by its edges from contributing its due share to the light.

As the angle is depressed, the light given increases, until in the neighborhood of 40 deg. depression the greatest light is given. After this it decreases rather rapidly to zero directly underneath the lamp.

Typical distributions of illuminating power are shown in the cuts, Figs. 410 to 414. The radius vectors of the curve indicate the relative illuminating power of the arc at the different angles indicated by the figures from 0° at the upper vertical to 180° at the lower vertical. 130° from the vertical is 40° from the horizontal, and this angle marks the line of greatest light.

The lower carbon, cutting off light by its shadow, is responsible for the diminution that increases so rapidly once the 135° angle from the vertical is passed.

It will be evident that it is impossible to express the value of an arc lamp in candle-power unless the same course is followed which is outlined above. It is taken in different directions, vary-



FIGS. 410 TO 414.—DISTRIBUTION OF LIGHT FROM OPEN-ARC LAMP.

ing from horizontal to vertical, thus giving eventually what is known as the spherical candle-power.

Commercial Rating of Arc Lamps.—A practice has arisen of calling the illuminating power of an arc lamp of standard street size 2,000 candles. This is a 480-watt lamp. Another standard size is the 300-watt lamp, rated at 1,200 candle-power. These values are far in excess of the spherical candle-power. But as it is the earth and not the sky which is to be illuminated, the

above figures are nearer the truth than they are usually supposed to be, if the value of the lower hemispherical candle power is taken.

Hissing Arc.—On being driven too hard, or with too much current, the arc makes a noise. Some change occurs at this point, because the voltage drops suddenly 10 to 20 volts, and with varying current gives a straight-line characteristic for the voltage, the voltage remaining unchanged for wide variations of current. No explanation that is satisfactory has been offered for this phenomenon.

Light Given by the Arc Proper.—It has already been noted that the positive carbon gives the most light. It gives 85 per cent of the light, the negative 10 per cent, and the arc proper only 5 per cent.

Resistance of Short Arcs.—When the current passing between carbons within less than 1/25 inch of each other is increased, the resistance does not decrease in the same proportion, and the product, R I, which by Ohm's law is equal to E, increases. Therefore the voltage drop with such short arcs increases with increase of current. If this condition held for commercial arc lamps, they could be used on parallel circuits at constant potential without wasteful resistance coils. The length of 1/25 inch seems to mark a point where the voltage remains constant for a wide range of current. This is because in the arc of this particular length the resistance diminishes exactly in proportion as the current increases, giving a constant value to the product R I or to E.

The Resistance of Longer Arcs on increase of current diminishes in more rapid proportion than with short ones, so that as current increases, the product R I grows less. This is why a resistance coil for each lamp has to be employed for constant-potential lighting, as explained on page 553.

From what has been said, it follows that on constant-current supply the energy expended in maintaining an arc will increase as the length increases, and with constant length will do the same as the current intensity increases. On trial the increase is found to be a proportional one in both cases.

Stationary State.—This is the state of normal burning of an arc lamp. When it starts, its constants vary until it reaches the

degree of heat due to the current and distance between the carbons. When this heat is reached, voltage and resistance remain constant as long as the length of the arc and the strength of the current are unchanged. In practical operation arc lamps are best operated in series. In this system the current is kept constant by the station management, and the regulators or lamp machinery maintain the distance between the carbons unchanged.

Alternating-Current Arc.—This type of arc consumes about the same watts in effective reckoning as the direct-current arc does. The 480-watt standard divides into 15 amperes and 30 or 35 volts. The volts are given in effective value, so the maximum value of the electromotive force is greater than the voltage of the same direct-current arc. The current value is greater in the alternating-current arc than in the direct-current arc. This compensates for the alternations, which would tend to produce flickering.

Power Factor in Alternating-Current Arc.—In the alternating-current arc the current lags about 30° behind the electromotive force. This introduces a power factor of 85 per cent of the apparent watts or product of effective current and potential drop.

Influence of Wave Form.—The efficiency of the alternating-current lamp is greater as its current curve avoids peaks and as its frequency is increased. It will be seen that the period of change of direction is a time when the carbon gets so little energy that it has to give light from its own acquired heat. The shorter this period, the greater is the efficiency, and therefore a high frequency is advisable for efficiency as well as for steadiness. A flat-tipped wave with quick or steep changes from one extreme to the other favors efficiency.

Distribution of Light of Alternating-Current Arc Lamps.—The light from a lamp does its work generally in the lower hemisphere of its distribution; the light cast out horizontally and at all downward angles is the useful light. This distribution is given by the direct-current arc lamp. The cratered upper carbon, in which the heat is concentrated, gives most light, and its light is principally thrown downward, and out horizontally. The light of the alternating-current arc is distributed alike up and down, and for this reason this arc is less advantageous than the

other. A reflector is often used to reflect the upward rays downward, but its effect is small.

Reactance Coil or Economy Coil.—Alternating-current arc lamps can be used on constant-potential circuit by the introduction in the circuit of each lamp of an inductance, a coil of wire with laminated iron core. A single coil with several intermediate connections may be used. These operate in a manner analogous to that of the individual resistance coil of a constant-potential direct-current arc lamp. They work by inductance, which is exceedingly economical as a reducer of current strength. It compensates in the case of constant-potential lamps for the otherwise low economy of the alternating-current lamp, and for its uneconomical distribution of light, as spoken of in the preceding paragraph.

Efficiency of Alternating-Current Arc Lamps.—The mean spherical candle-power for equal watts is put at one-half that of the direct-current arc lamp.

Noise.—The alternations in the current and the effects of the corresponding induction on the laminations of some of the parts caused considerable noise. In modern construction the latter noise is prevented by clamping fast all vibrating laminations of iron, and by the use of springs and India-rubber supports for such parts, so as to prevent anything like sounding-board action. The application of the inclosed-arc principle operates to greatly diminish the hum of the arc.

Duration of Carbons.—The alternating-current inclosed-arc lamp with a 6-inch lower and 9½-inch upper carbon burns about 80 hours before the carbons need renewal. The direct-current inclosed-arc lamp may run 100 to 150 hours before the carbons need changing. This is to be compared with 8 to 10 hours' duration for open-arc lamps.

Length of Arc.—The alternating-current arc is in practice about ⅜ inch with a 6-ampere current and 70 to 75 volts. This is quite different from the direct-current factors of working.

Inclosed-Arc Lamps.—The original arc lamp of the early days of electricity, with charcoal electrodes made conducting by impregnation with mercury, was of very short duration as regarded its carbons. It was only experimental, was actuated by a primary

battery which soon expended itself, and awaited the development of some cheap source of electricity to become practical.

When the modern dynamo gave large quantities of electric energy, many forms of arc lamp were devised, depending for the durability of their carbons on the composition of the same. These were made hard and relatively incombustible, but in the intense heat of the arc they burned away quite rapidly and had to be frequently replaced. On every replacement a stump of more or less considerable length was lost and thrown away.

About 1882 attempts were made to follow in the wake of the incandescent lamp, and to inclose the arc in an air-tight globe. In 1894 successful inclosed-arc lamps were produced, and now the movement is for their universal use.

It is evident that an hermetically-sealed globe is almost an impossibility for an arc lamp. The carbons are certain to be reduced as the lamp burns, irrespective of combustion. The arc wears away the carbons mechanically by its transfer of carbon particles from one carbon to the other. The problem of inclosing and protecting the carbons is solved by using an approximately tight globe. The carbon is fed through a hole in the top, which it almost fills. The globe is otherwise closed. A very little air gets in by diffusion, but the duration of the carbons is increased very greatly.

On standing idle, the globe slowly fills with air. On starting the arc, combustion of the carbon begins, and in a few minutes the oxygen in the globe is exhausted, being replaced by carbonic-oxide and carbonic-acid gases, and the wasting of the carbons is now mechanical for the most part.

The Action of the Inclosed Arc is to transport carbon particles from the positive carbon to the negative. These particles impinging on the hot negative carbon stick there, and tend to form a little lump upon it. The positive carbon wears away, with a slight tendency to become concave or a very little hollowed at the end. The negative has the opposite tendency, becoming slightly rounded. If the carbons are started with the usual pointed ends, they soon become almost flat-ended.

The object being to preserve the shape of the carbon ends, the more or less irregular deposit of carbon particles on the negative

electrode is a disadvantage. The carbon particles do not all deposit on the negative, but also tend to form a blackish coating on the glass. If the globe were hermetically sealed, the glass would inevitably blacken. Recourse is had to the air as a cleaning agent. Enough finds its way into the globe to burn up the carbon particles and vapor and prevent it from forming the deposits on the glass and on the negative carbon. The present successful form of inclosed-arc lamp is the product of years of experimentation and gradual development.

The General Electric Company inclosed-arc lamps have a combined globe and lower carbon holder. The lower carbon is held stationary, all the feed being done by the upper carbon. This feature enables the trimmer to remove the lower carbon and globe together and replace them by a clean globe and new lower carbon. The globe removed can be returned to the station for cleaning. The inclosing globe is comparatively small, 6½ inches high by 3 inches diameter. A small passage several inches long in the cap connects the space inside the globe with the air. The idea is to have the passage act as a gas chamber to prevent the direct access of air.

Globe and Carbon Holder.—This is shown in Fig. 415. B is the globe holder which is seen rising from it, and in its center are shown the lower carbon and the lower end of the upper carbon. The head of the screw for fastening the lower carbon faces the reader. A is the holder for the outer globe, which is held from shaking by the spring *b b*, which goes inside it. The frame carrying it is drawn down. When the lamp is in use, the frame is pushed up, the clamp C enters the slot at D, and by turning the clamp through 90° all is secured.

Inclosed-Arc Lamp Carbons.—In inclosed-arc lamps of standard size, ½-inch carbons are used. The upper one is for direct-current lamps 12 inches and the lower one 5 inches long. The upper one wearing away twice as fast as the lower one, becomes too short after long burning. Before it loses more than half its length, the lamp has to be trimmed. This is not only necessary for the replacement of carbons, but also for cleaning the small globe. A certain amount of carbon dust and ashes collects in the inclosing globe, which has to be cleaned.

The short lower and negative carbon becomes reduced to a mere stump, and can without much waste be thrown away. The upper carbon, about half its former length, is preserved and is cut down to the standard length of 5 inches, and is used as the lower carbon.

A lamp of this type burns for 125 hours or for 10 or 12 nights without trimming.

One characteristic of inclosed arcs affects the shape of the carbons. They burn with approximately flat ends. This undoubtedly hurts their efficiency by screening off the incipient crater or hottest point on the positive. The flat opposing negative and the projecting area of the positive operate to produce this screening.

On 110-volt constant-potential circuits a lamp will take 80 volts; on 120-volt circuits it will take 85 volts. The remainder is taken up and lost in the resistance coils which are used on constant-potential systems.

The Clutch.—The development of arc lamps was marked by the most important application of the clutch to the carbon feed. The cut, Fig. 416, shows one of the original forms, the old Brush clutch. It is designed as shown to feed two carbons. It consists of a flat plate W with a hole slightly larger than the rod or carbon R which passes through it. When its end is lifted by the mechanism operating K, the plate binds or grips the rod and raises it. When the end is lowered, rod and clutch descend together, the clutch not losing its grip until the outer free end is arrested in its descent. The clutch is then said to trip. As it approaches the horizontal position on being tripped, the grip ceases, and the rod descends through it.

In Fig. 417 is shown a modern clutch. When the lever F is raised or as long as the weight of the carbon is sustained by it, the upper end C of the shoe is pressed against the carbon or carbon rod A, and grips it between itself and the upper end of D. As the carbon burns and is fed down a little, the tripping piece E touches the tripping platform G, and the lever F descending, the grip opens and the carbon can drop down. The lifting position is shown in the left-hand figure, and the releasing position in the right-hand figure. A still simpler clutch is shown in Fig. 418. It is used in the General Electric Company's arc lamps.

Tripping Platform.—This name is given to the little platform or plate which the clutch comes in contact with on its descent, and contact with which trips it, and causes it to relax or lose its grip upon the rod. In Fig. 417 a tripping platform is seen at G.

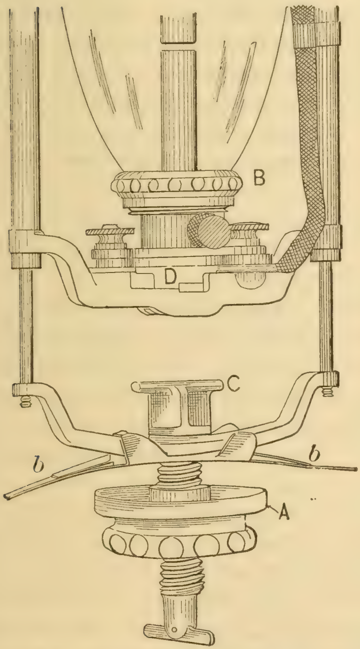


FIG. 415.—GLOBE HOLDER OF INCLOSED ARC LAMP.

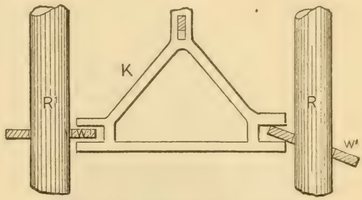


FIG. 416.—BRUSH CLUTCH.

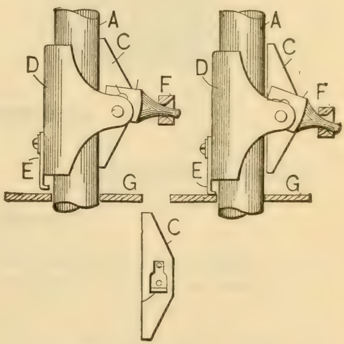


FIG. 417.—ARC LAMP CLUTCH.

It is also shown in Fig. 422 directly above the lamp globes and below the clutches.

Carbon-Feed Lamps.—The clutch is used for almost all commercial lamps. It may grip a brass rod or tube to whose lower end the carbon pencil is secured. The advantage of this arrangement is that the clutch has always the same cylinder to act upon. In many lamps the clutch grips the upper carbon directly. Such

lamps are said to have a carbon feed. The carbons for such must be of uniform shape, and but a very slight variation in diameter is admissible.

Concentric Magnets.—In some lamps a single magnet coil is used, placed directly in the axis of the lamp. A plunger works up and down within the coil and operates the feeding mechanism. In other types of lamps the magnet coils are placed to one side of the axis. In Fig. 419 is shown the type used in some of the General Electric Company's lamps, a U-shaped magnet with double-plunger armature.

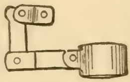


FIG. 418.—ARC LAMP CLUTCH.

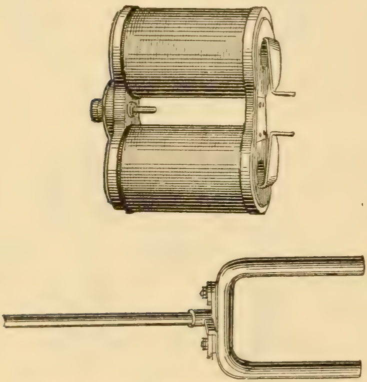


FIG. 419.—ARC LAMP MAGNET WITH DOUBLE-PLUNGER ARMATURE.

Dash Pots.—A dash pot, Fig. 420, is a cylinder with a piston. Owing to the slow escape and ingress of air, the piston cannot move rapidly up or down, although it is devoid of friction as far as possible. Thus, it is quite free to take any position, but is not free to do so rapidly. The piston is attached to one of the armature parts in arc lamps, so as to rise and fall with the armature. While entirely without effect upon the position ultimately taken by the armature, it prevents all sudden movements and secures steady carbon feed.

Carbon Holders.—The lower carbon does not move, and is set into a socket, as shown in Fig. 415. This may have a setscrew to retain the carbon firmly in position. An upper carbon holder is often a short tube, Fig. 421, whose lower end is slotted and springs over the upper end of the lower carbon; the wire from the line connects to the top of this holder. The holder slides up and down in a long vertical tube in the axis of the lamp. Its mo-

tions are governed by the magnets and clutch mechanism. In the diagram, Fig. 422, the tube is seen in a vertical position directly over the carbons, and within it is seen the carbon holder with the leading-in wire coiled in the tube above it.

Constant-Current or Series Arc Lamps.—In operating arc lamps on series, a constant current is forced through the line. The length of the arc cannot therefore be regulated by the current in series, as the latter is invariable. The carbons in a single lamp may be drawn so far apart as to greatly increase the resistance and disturb the working of the entire series of lamps. This possible trouble has to be provided for also in constant-current lamps.

FIG. 420.—DASH POT.

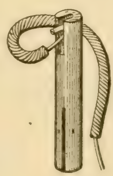


FIG. 421.—COPPER CARBON HOLDER.

Two magnets are used to operate the clutch. One magnet is in series with the lamp, and when the current is turned on, the clutch is raised, lifting the upper carbon, which when the lamp is idle rests upon the lower one, and causes the arc to strike. This ends the functions of the series magnet until the next period of lighting comes.

A second magnet is placed in parallel with the arc. As the arc increases in length, the resistance of the arc also increases, and more current is shunted through the shunt magnet. This magnet is so connected to the clutch that as it attracts its armature and the latter rises, the clutch descends, thus shortening the arc.

If for any cause the arc should become too long, so as to require two or three more volts for its maintenance than proper, the mechanism closes a cut-out, which operates by closing a circuit in parallel with the lamp. If the carbons descend, and the ends come in contact because the clutch trips and refuses to act, the cut-out also closes. Thus the cut-out becomes operative at either extreme.

The diagram, Fig. 422, illustrates the action. It shows the lamp

inactive, the carbons in contact, and the cut-out closed. If current is turned on, it goes through the cut-out. In series with the cut-out is a coil which provides the starting resistance. Its resistance shunts sufficient current through the series magnet to cause it to attract its armature and raise the clutch. This separates the carbons, the arc strikes, and current is shunted through the shunt magnet. This at once begins to regulate the length of the arc.

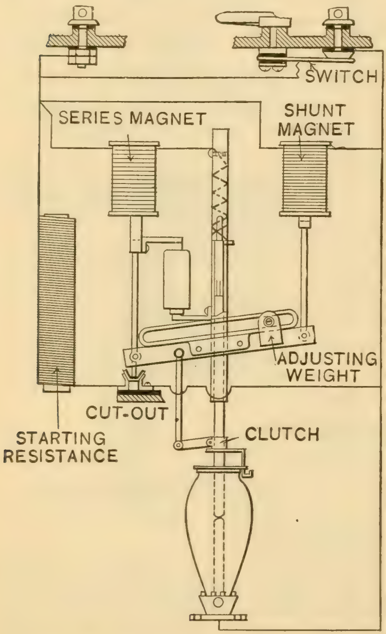


FIG. 422.—DIAGRAM OF CONSTANT-CURRENT SERIES ARC LAMP MECHANISM.

The armatures of the shunt and series magnets operate a rocker arm which is pivoted between the magnets, so that the series and shunt magnet have reverse effects on the movable upper carbon. As the shunt-magnet armature is drawn up, the clutch descends, owing to the action of the rocker arms, and the reverse action takes place when the shunt-magnet armature descends. In this way the increase of arc length shunting more current through the shunt magnet causes the clutch to descend and the arc shortens. The dash-pot is shown to the left of the central tube above the rocker arm. Immediately below the clutch is the tripping platform, seen extending over the top of the globe.

Adjusting Weight.—This slides back and forth upon the rocker arm attached to the two armature rods. This is fastened in any desired position by a setscrew. For variations in current exceeding 0.2 ampere above or below the rated current of the lamp,

the weight must be shifted. Moving the weight toward the clutch rod reduces arc voltage, and moving it away increases arc voltage.

Fig. 423 shows the lamp with the cover removed from the mechanism. The parts can be identified by the diagram, Fig. 422.

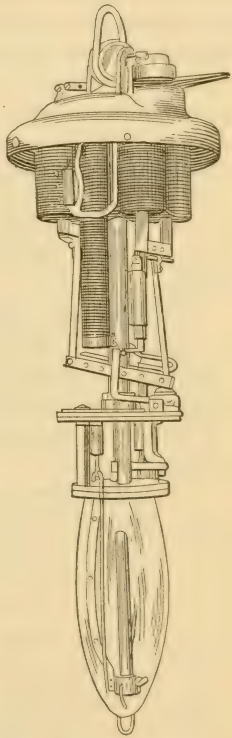


FIG. 423.—CONSTANT-CURRENT SERIES ARC LAMP.

Action of an Arc Lamp on a Constant-Potential Circuit.—The resistance of the arc decreases as the current increases, and *vice versa.* Therefore on a constant-potential circuit, where the current is practically unlimited, an arc lamp cannot be used without auxiliary apparatus. The resistance coil in the case of the direct-current arc lamp, and the inductance coil in the case of the alternating-current lamp, are the auxiliary apparatus preventing this action.

Action of the Resistance Coil in a Constant-Potential Arc Lamp.—A momentary increase in the current through a lamp without a coil would lower its resistance so that too much current would pass, and the current would increase until some damage would ensue or until a fuse would blow out. But a fixed resistance in series with the lamp prevents this trouble. By Ohm's law, $E = RI$, with fixed resistance the drop required to force a current through the resistance will increase or decrease in proportion to the current. The drop of potential expended on the lamp alone is a fixed amount, that of the potential of the system minus the drop expended on the resistance coil. The moment the current increases in the lamp, the drop in the resistance coil is increased and that in the lamp is diminished. This reduction of drop cuts down the current again to its proper amount.

A momentary decrease in the current, on the other hand, in-

creases the resistance of the lamp, which cuts down the current still further, and the lamp may be quite extinguished if without a series resistance. But with a resistance in series the action converse to that just described takes place. A reduction of current through the lamp and resistance coil can only be due to an increased resistance in the lamp. This decreases the drop in voltage due to the resistance coil; and as the dynamo maintains a constant voltage, the drop at the lamp is increased. This operates to give more current to the lamp, compensating for its increase in resistance.

The reactance coil in series with the alternating-current lamp acts in the same way, except that reactance of induction plays the principal *rôle* in steadying the lamp, resistance being quite secondary.

An additional regulating action of the series resistance may be sought for in its variations in temperature. As more current passes, it gets hotter and increases in resistance. This is exactly what is wanted; but whether this action is ever sufficient in extent to play any part in the actual regulation is problematical in most cases.

A standard potential for constant-potential systems is 110 volts. This, of course, varies considerably in different parts of a district, but it gives a basis for parallel circuit arc lighting. Forty to fifty volts are the drop for a commercial open-arc lamp. Two in series with a steadying resistance will meet the voltage of the incandescent system. This has become a general method of disposing of them. They take some ten amperes of current, so that each group of two in series represents in current consumption twenty incandescent lamps in parallel.

The Parallel-Circuit System of Electric Supply is very extravagant in first cost of installation. A district could have its illumination supplied by incandescent lamps in series of twenty or more through a network of comparatively small wires. Roughly speaking, one extreme would be the case where the copper mains which would supply the lamps would be of but one-twentieth the size of those required on parallel circuit for the same lamps.

First cost of installation is capitalization, and interest has to be paid upon it, so that heavy copper mains and large current

machines are a source of annual expense just as much as coal consumption. An arc lamp gives far more light per unit of power than an incandescent lamp. Placed in parallel circuit it exacts large mains, and the resistance in series consumes energy.

The series connection is the ideal system for arc lamps. They are used for continuous or periodic illumination, are not supposed to be lighted and extinguished by consumers, and the use of them on parallel circuit is a concession to an existing state of things only. No engineer would primarily establish a parallel system of arc lighting.

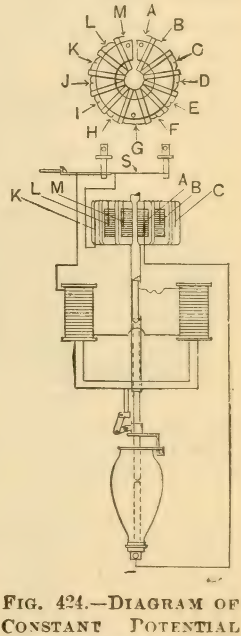


FIG. 424.—DIAGRAM OF CONSTANT POTENTIAL ALTERNATING-CURRENT ARC LAMP MECHANISM.

Constant-Potential Arc Lamps.—This class of arc lamp operates on constant-potential circuits, and its regulating magnet is operated by variations in the current. An increase of current causes the magnet to lift its armature, and thereby to lift the upper carbon. This increases the length of the arc and its resistance and reduces the current. A diminution of current permits the magnet armature to descend, the upper carbon descends with it, and the arc is shortened. This reduces the resistance of the arc and increases the current. The increase of current arrests the downward movement of the armature, and may cause it to rise a little. These converse actions keep the length of the arc approximately the same.

The diagram, Fig. 424, shows the principle of construction of a constant-potential arc lamp of the General Electric Company. The one illustrated is an alternating-current lamp. For the purposes of this description the principal difference between it and a direct-current lamp is the use of a reactive coil instead of a resistance coil. The current enters by a binding post, passes through the reactance coil, the lower carbon, arc, and upper car-

bon in the order named. It then passes through the magnet coils and out on the line. The armature is of double-plunger type, with the lower end of the plungers connected by a cross bar which carries a downwardly projecting rod at its center, which operates the clutch as shown. Immediately below the clutch is a tripping platform. When the clutch strikes this it trips, and the carbon drops a little. Another distinction between the constant current lamp and the constant potential lamp is that the latter has only one regulating magnet, which is in series with the arc.

The reactance coil is shown in horizontal diagram above the lamp. The lettered places indicate points of connection for the

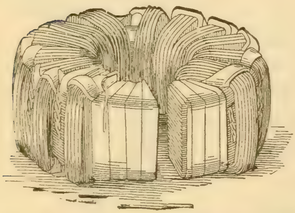


FIG. 425.—REACTANCE COIL FOR CONSTANT POTENTIAL ALTERNATING-CURRENT ARC LAMP.

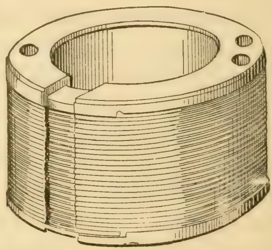


FIG. 426.—RESISTANCE COIL FOR CONSTANT POTENTIAL DIRECT-CURRENT ARC LAMP.

wires. The wire T, the right-hand one in the cut, is always connected to point A or B'. The wire S, over the top of the lamp, is connected to any of the other points according to the voltage on the circuit and the frequency of the circuit. The arc voltage is taken at 70 to 73 volts. For 60 cycles and 104 volts on the line, S should be connected probably to J; for 125 cycles and 104 volts, to F. To increase arc voltage fewer coil divisions must be brought into series. Thus, changing the wire S from M to L or to K increases the voltage of the arc by cutting out part of the reactance of the coil.

The direct-current lamp is of the same construction, except that it contains no reactance coil, but a resistance coil wound upon a grooved porcelain block occupies the same place. A sliding contact arranged in a groove shown on the side of the porcelain

block enables the resistance to be regulated by rheostat action.

Fig. 425 shows the reactance coil, and Fig. 426 the porcelain block for resistance coil. The groove on the side receives the

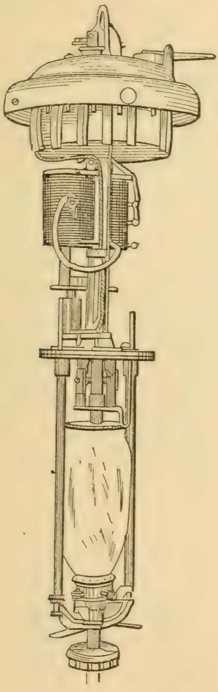


Fig. 427.—Constant Potential Alternating-Current Arc Lamp.

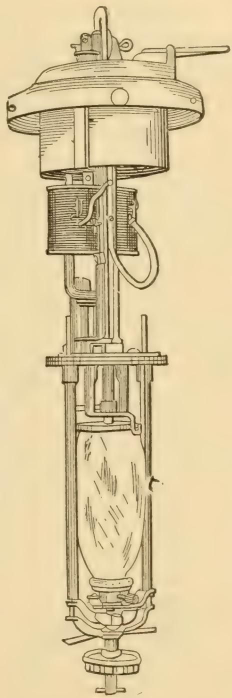
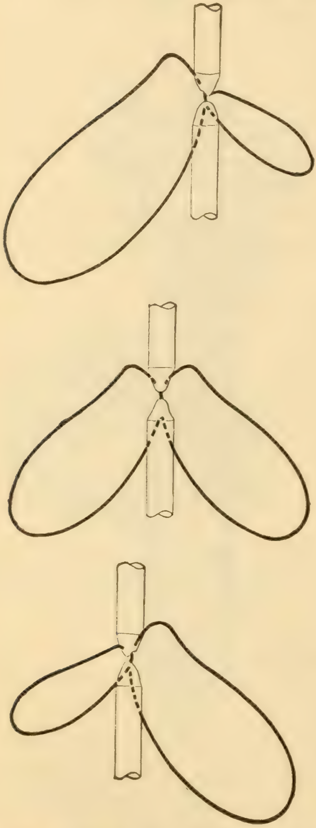


Fig. 428.—Constant Potential Direct-Current Arc Lamp.

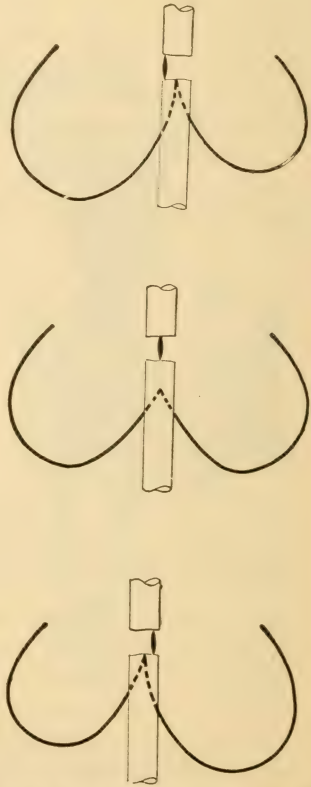
sliding contact piece used to cut out resistance as desired. The alternating-current lamp is shown in Fig. 427, and the direct-current lamp in Fig. 428.

In both types of lamp the arc is liable to travel from side to side of the space between the carbons. The effect on the distribution of light is quite different in the inclosed and open arc

lamps, and is illustrated in Figs. 429 to 434. The distribution of light from the open arc lamp with central and side arc is shown in



FIGS. 429 TO 431.—DISTRIBUTION OF LIGHT IN DIRECT-CURRENT OPEN-ARC LAMPS.



FIGS. 432 TO 434.—DISTRIBUTION OF LIGHT IN DIRECT-CURRENT INCLOSED-ARC LAMPS.

Figs. 429 to 431. The crater in the upper carbon is so displaced by the migrations of the arc as to make a great difference in the amount of light given on the side where the arc is, compared with that given by the other side. Figs. 432 to 434 show the ef-

fect of the migration of the arc in direct-current inclosed-arc lamps. As only a slight crater forms in the carbons of this type of lamp, the unevenness of distribution of light due to shifting of the arc is very slight.

Management of Inclosed-Arc Carbons.—To get the longest life out of the carbons, the following rules should be observed. The lamp should not be run on a circuit of frequency or voltage different from that for which the lamp was adjusted. A lamp when burning should have at least 100 volts drop at the arc. The carbons in inclosed-arc lamps are separated by twice the interval which obtains in the open-arc lamps. The inclosing globe must fit perfectly. Its upper edge must make a virtually air-tight joint with the cap. The mechanism must work freely, so as to insure correct feed. The old upper carbons can be cut to proper length if too long, and used as lower carbons. Carbons should not be used of length greater than that specified for the lamp.

Adjusting Lamps.—Lamps are usually sent out adjusted for the voltage or current which the purchaser has specified in his order. A variation of a quarter of an ampere above or below the rated current calls for adjustment. In the General Electric Company's lamps a weight is sometimes mounted on the working lever. This weight can be shifted so as to adjust the lamp for different currents. Moving this weight toward the clutch rod reduces the voltage or drop at the arc; moving it in the other direction increases it, as it acts to pull the carbons apart.

The Inclosing Globes.—The directions for installing lamps issued by the manufacturing company sometimes specify that the lamps should not be started without the small inclosing globe being in place. This instruction should be rigorously followed. The inclosing globe is as much a part of the lamp as the carbons are. Not only the rate of consumption of carbons is reduced by the presence of the globe, but the carbon ends take a different shape. The reduction in consumption of carbons is important as an economy in supplies, and because it diminishes the labor bill for trimming. The inclosing globe is subjected to strong heat. It must not be clamped so tight as to break for lack of room to expand. The hole for the upper carbon must be a good but perfectly loose fit. The little air which works in through it

is rather a benefit than otherwise, as it tends to keep the lamp cleaner.

Negative and Positive Connections in Inclosed-Arc Lamps.—If a direct-current arc lamp is to be installed, the upper carbon must be connected to the positive terminal of the line. If there is any doubt about the connections, the current may be turned on for a few minutes and then turned off. If properly connected, the upper carbon will be the hotter, and consequently will remain red hot longer than the lower one will. If improperly connected, the lower carbon will be the hotter. In such case reverse the connections.

Putting a Lamp Into Service.—After unpacking a new lamp remove the upper casing. This is sometimes secured by a bayonet joint, sometimes by screws. Sometimes wedges and packing are used for safety in shipping. Such will be seen inserted in the machinery, if present. Remove them carefully, brush out the machinery if necessary, examine it for loose parts, and see that the movable parts work freely. When all is in order, replace the casing. Sometimes lamps are shipped with the lower carbon holder and its rod removed from the lamp. If so, it must be put into place. Care must be taken in doing this to center accurately the lower carbon. This is effected by putting the lower carbon rod in its right position. Then perfectly straight carbons should be used. If they do not come in line, the lower carbon holder may in some lamps be used to rectify their position by twisting.

Oil.—Do not oil the dash pot or other mechanism of an arc lamp. Its parts are so exposed that lubrication is inadvisable.

Clutch Stop Adjustment.—The clutch stop should be so adjusted that with the carbon of smallest allowable diameter the upward movement of the clutch is arrested when the armature is within one-eighth to one-quarter inch of the magnet pole faces.

Cut-Out.—The cut-out is adjusted to close when the stem of the clutch is about one-sixteenth inch below the tripping point. The lamp should with this adjustment cut out when the voltage is two or three volts above the feeding voltage.

Carbons for Inclosed-Arc Lamp.—For satisfactory operation of an inclosed-arc lamp, one cored and one solid carbon should

be used. In ordering, half of the order should be for solid and half for cored carbons. They may all be of the same length, say twelve inches. When the lamps are started, the lower carbons can be got by cutting 12-inch carbons into pieces. Afterward the partly-burned upper carbons will act as lower carbons. The carbons must be smooth and of even diameter. The upper one is supposed to act almost as a stopper for the upper hole in the inclosing globe's metallic cap. Any friction at this point will interfere with the feed of the upper carbon and may put the lamp out.

To Carbon a Lamp.—The following directions are given by the General Electric Company for their series inclosed-arc lamps. Be sure that the current is switched off. Hold the inclosing globe firmly and swing the bail to one side after pulling down on it. The globe will come off. Loosen the setscrew and remove the lower carbon. Remove the upper carbon, and put in a new one, inserting it in the spring carbon holder of the upper carbon tube. Put a lower carbon of proper length in the lower holder, and secure it with the thumbscrew. Replace the inclosing globe, being careful to set the upper edge squarely against the finished surface of the cap, so as to exclude the air from the arc. Secure the globe by placing the supporting ring of the bail around the projection on the bottom of the globe. To insure proper electrical connection to the upper carbon, it must be well inserted in the spring carbon holder on the inside of the carbon tube. The insertion of the carbons into the holders is facilitated by their having beveled ends. The inclosing globe should be cleaned at the station periodically, or the dirt which collects on its inner surface will reduce the light. The above directions have to be modified for lamps with inclosing globes of other type. The modifications are obvious on inspection of the lamp.

Lamps Without Mechanism. The Jablochkoff Candle.—At one time the efforts of inventors were directed to the end of producing an arc lamp without mechanism, but all such have practically gone out of use. The Jablochkoff candle, illustrated in Fig. 435, had very extensive use at one time. It consisted of two parallel rods of carbon separated by an insulating material, such as gypsum. They were used necessarily with an alternating cur-

rent. A small bit of carbon was laid across the top to connect the carbons. This enabled the current to start, and in a few seconds the carbon slip burned away and the arc was formed. In the cut *d d* are the line connections, *b* is a spring keeping pressure upon the socket holding the base *a* of the candle. Once the arc was formed, it was supposed to continue until the candle burned out. If the arc went out, it would not form again.

The Wallace Lamp, an American invention, is deserving of notice, although it was never much used. The carbons were in the form of two rectangular plates. By regulating mechanism they were kept edge to edge within a fraction of an inch of each other. The edges were sensibly parallel to each other, but inevitably one place would mark a slightly closer approximation of the carbons. Here the arc sprang across, and as it burned, increasing the distance, it shifted a little, and eventually traveled the whole length, several inches in extent, of the edges of the carbon plates. As the distance between the edges increased, the upper plate was fed down so as to diminish it.

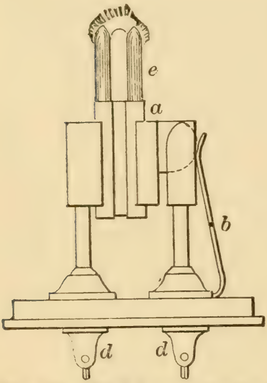


FIG. 435.—THE JABLOCHKOFF CANDLE.

The Sun Lamp had two inclined rods of carbon occupying a position like that of the two arms of the letter V. They descended through holes in a block of refractory material by their own weight.

Open-Air Incandescence.—One modification of the true arc lamp has disappeared from the field. Open-air incandescence was the name given to the principle on which this class of lamps operated. This principle utilized the loose contact between a carbon point resting on a carbon surface as the seat of incandescence. This secured a simple gravity feed, and to a considerable extent got rid of mechanism.

Gradually all these lamps died out, and at the present time arc-lamp lighting is fast settling down into the use of the inclosed-arc lamp with positive downward feed of the upper carbon.

CHAPTER XXXIII.

PHOTOMETRY.

Standards of Illuminating Power.—The light given by a source of illumination, such as a gas flame, oil lamp, or electric lamp, has in the existing state of science to be referred to and measured by some standard. The usual standard in this country is the candle. This is a sperm candle burning 120 grains per hour.

Many other units of illuminating power have been proposed, and in other countries they have been adopted to a greater or less extent. A number of the more prominent are summarized below, with their relative values.

The light given by a lamp is called indifferently its illuminating power or its candle power. The latter term does not apply to French practice, where the Carcel lamp (Bec Carcel) is the standard.

Principle of the Photometer.—The principle on which the testing of lamps for candle-power is based is the following. The source of light is assumed to be a point. As the distance of the observer from it is increased, he receives less light. The degree of light received is dependent on the area over which its effect is spread, and like all radiations its intensity varies inversely with the square of the distance.

The cut, Fig. 436, shows this clearly. The larger area has distributed over its surface the exact amount of light which lights the smaller area. One is twice as far removed from the source of light as is the other, and its area is four times as great. Therefore, a portion of the area of the distant surface equal in area to the nearer one receives one-quarter the amount of light, because it is at double the distance.

Suppose two lights are placed at a distance of 90 inches from each other, and a screen is placed at a point on the line connect-

ing them where it will receive an equal amount of light from each. Suppose that this point is 60 inches from one light and consequently 30 inches from the other. The ratio of 60 to 30 is as 2 is to 1. As the light given varies inversely with the square of the distance, it follows that the nearer light is of one-quarter the power of the distant one.

Bar Photometer.—The above is the principle of the bar photometer, the instrument universally used for testing the candle-power of lamps, as well as of the shadow and other less used apparatus.

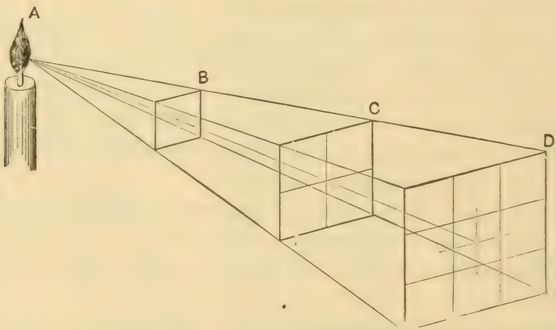


FIG. 436.—LAW OF THE INVERSE SQUARES.

Photometric Screens.—A screen is used to determine the point on the bar at which an equal amount of light is received from both sources. Several devices have been employed or suggested for this purpose.

The Bunsen Disk.—The Bunsen disk is founded on the following principle. If a spot upon a sheet of paper be treated with grease, it will become more translucent and less reflective than it was before. Therefore, if seen by transmitted light, if held between the observer and a candle, for instance, it will appear lighter in color than the rest of the paper. If light is caused to shine upon it, then the spot will appear darker than the rest of the paper, because it does not reflect light so well.

If such a piece of paper is held between two sources of light and receives the same amount of light from each, the spot will

tend to disappear. It may not disappear completely, but the position of greatest faintness is easily found with considerable accuracy.

The disk is made of rather heavy white paper, and the spot in the center is made by melting paraffin wax into the paper. Any kind of greasy matter will do as an expedient for temporary purposes. A hot bit of wire will answer for melting it into the paper. The translucent spot should be about an inch in diameter. Sometimes the spot in the center is the untouched paper, and the paraffin is melted in a ring surrounding it.

The Leeson Disk.—This screen is of the simplest description also. A star is cut out of a piece of heavy note paper. It is laid between two pieces of thin note paper. In use the screen is moved to such a position that the star appears equally bright on both sides of the disk.

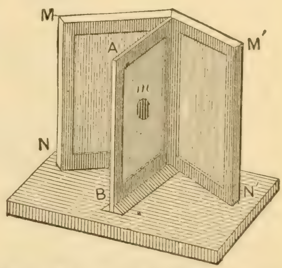


FIG 437.—THE BUNSEN DISK MOUNTED BETWEEN TWO MIRRORS.

Mounting the Disks.—The disk or screen should be three or four inches in diameter. It is mounted on a block of wood which slides upon the bar. The observer then looks first at one side and then at the other, shifting it back and forth until the spot nearly disappears. It is then receiving the same amount of light from both sources, and the reading on the bar gives the relative intensity of the lights. Sometimes the disk as shown in Fig. 437 is mounted between two mirrors. A B is the frame carrying the disk, M N and M′ N′ are the two mirrors. This enables the observer to see both sides of the disk without moving his head. A disk mounted in this way between mirrors is often carried in a little car which runs along the bar. The center *m* of the disk should be on the level of the two lights which are being compared, and directly between them.

The Lummer-Brodlum Screen.—In this screen the observations are made with a single eye, eliminating it is claimed any chance of error due to unequal sensibility of the two eyes. The diagram, Fig. 438, represents the horizontal plan of the apparatus. It is

supposed to be mounted on the photometer bar. C indicates the standard lamp, X the light which is being tested. S is an opaque white screen of plaster of Paris; both sides are illuminated, one by each light, C or X. At M and N are mirrors which reflect the light to the prisms, the beams falling normally or perpendicularly upon the face of the prism receiving it. Each prism has a spherical

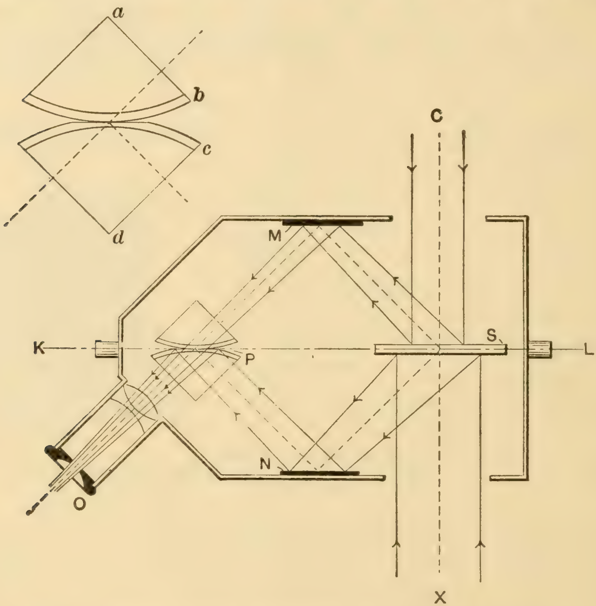


FIG. 438.—LUMMER-BRODLUM PHOTOMETER SCREEN.

face, and a circle is ground upon the center of each face, one circle being larger than the other. When placed in contact, flat side against flat side, there is a circle of contact, surrounded by the outer parts of the larger circle, which is not in contact with the other prism. Light reflected from the mirror N passes through the circle of contact to the observer's eye at the end O of the sighting tube. The circle of contact shows the degree of illumination of the side of the screen S facing C and lighted by it.

The light from the side of the screen S, due to X, reflected from

the mirror N, goes to the double prism also. The portion of the beam which impinges on the outer flat circle is reflected to the observer's eye at O. The observer therefore sees a circle through which light from C passes, surrounded by a circle from which light from the screen S due to X is reflected. If the screen is moved back and forth upon the bar, a point will be reached when each side of the screen will receive the same intensity of light. At this point the central circle and outer circle will appear of equal brightness. The back of the outer circle is blackened, and total reflection of the light falling on it ensues.

It is estimated that the mean error of setting this screen does not exceed five per cent, and that it is four or five times as accurate as the ordinary Bunsen or Leeson disks.

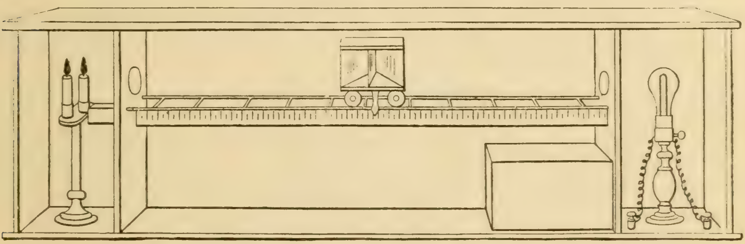


FIG. 439.—THE BAR OR BUNSEN PHOTOMETER.

The Standard English Candle.—This, which is the American standard also, is a sperm candle burning 120 grains of sperm per hour. It is the commercial article made of a mixture of wax and sperm, and with a plaited wick. When in good condition the wick should bend over and have a red end. If it burns more than five per cent too much or too little, the readings are to be distrusted. The standard candle in hot weather is apt to burn too much sperm, and give too high a value to the lamp which is being tested. This is sometimes overcome by putting the candles on ice for an hour before they are used. At best, it is so very poor a standard that the wonder is that it has so long been used.

The Apparatus.—The general disposition of a photometer is shown in the cut, Fig. 439. In it are shown the divided bar,

with an electric lamp to be tested at one end of it and the candles at the other. The box holding the disk and mirrors runs upon wheels along the bar. The apparatus is contained in a room with blackened walls. A curtain may be used to further inclose it.

Calculating the Scale of the Bar.—It would be a simple matter to use a bar divided into inches and fractions of inches. Then by placing the screen at a distance where it would be equally illuminated on both sides, the distances of the two lights from it could be squared, and their inverse ratio would give the relative illuminating power as above. It would be more convenient to have the bar so divided as to give by its direct reading the relative value of the two lamps. This system of dividing is frequently followed. It may be done by the following process:

Let $1 =$ value of standard light at one end of bar.

Let $v =$ value of lamp to be tested at other end of bar.

Let $100'' =$ length of bar.

Let $x =$ distance from 1 to screen.

Then $100 - x =$ distance from v to screen.

The light-giving value varies inversely with the square of the distance; the more powerful light gives an equal illumination at a greater distance than does the weaker one. This gives the proportion and resulting equation:

$$1 : v :: (100 - x)^2 : x^2 \text{ or } v = \frac{(100 - x)^2}{x^2}$$

$$\text{Let } v = 2\text{; then } \frac{(100 - x)^2}{x^2} = \frac{2}{1}$$

To obtain the place on the bar where this ratio holds, the square root of both members of the expression $\frac{2}{1}$ must be extracted. This gives $\frac{1.414}{1}$ as the ratio in which 100 inches must be divided. It may be done by proportion, thus:

$2.414 : 1.414 :: 100 : x = 58.58$ inches.

Therefore, at points 58.58 inches from each end a 2 is to be marked on the bar.

$$\text{Next let } v = 3\text{, and we have } \frac{(100 - x)^2}{x^2} = \frac{3}{1}$$

The square root of 3 is 1.73; the ratio of parts of the bar is $\frac{1.73}{1}$ which by the proportion

$$2.73 : 1.73 :: 100 : x = 63.37.$$

gives 63.37 inches as points measured from right and left ends of the bar on which the figure 3 must be marked.

This is the simplest method as regards the arithmetic of the process by which the division can be effectually effected. As executed above, the decimals are not carried out as far as they should be. It is a case in which the work should be done by logarithms, not only for the sake of expedition, but to avoid errors in the operation.

The Observation.—The candles—for in modern practice two are generally used simultaneously to give an average—are lighted and allowed to burn some five or ten minutes. They are placed on a balance and weights adjusted so as to make their end of the balance beam a few grains the heavier. As they burn they get lighter, and soon overbalance. The lamp to be tested is lighted and a voltmeter and ammeter are arranged for reading. The instant the candles overbalance, the time is taken and written down. The candles are carefully placed in position at their end of the bar, and the readings are taken every half minute until ten readings have been taken. At exactly five minutes from the time noted, the candles are carefully blown out. If the ends stay red, they must be bent down with a pin until they absorb melted sperm, when they will at once expire. If the candles are not carefully blown out, grease will fly about, and the candles will lose weight. The candles are now weighed, and their percentage error is deducted or added to the average of the photometer readings.

Suppose the candles burned 19.2 grains. This is an error of four per cent, for two candles in five minutes should burn 20 grains of sperm. The candles gave too little light as they should have burned 10 grains in five minutes. Therefore four per cent has to be subtracted from the average reading.

The candle balance is often mounted at the end of the bar, so that the candles are weighed there, and never need to be moved from their position.

Other Standards.—The French standard is the Carcel lamp, accurately defined as to its dimensions, and burning 42 grammes of colza oil per hour. Many precautions to be observed with the Carcel lamp have been formulated by MM. Dumas and Regnault. The German standard is a paraffin candle burning with a flame of 50 millimeters (1.98 inches) height. The Munich standard is a stearin candle consuming 10.4 grammes of stearin per hour. The Violle standard, adopted by an international conference of electricians, is the light emitted by a square centimeter (0.39² inch) of platinum at its temperature of solidification. It is not adapted for ordinary use, and it is questionable if it should ever have been adopted. The Heffner-Alteneck lamp is a simple round solid-wick lamp burning amyl acetate with a flame exactly 1.57 inches high and regulated for each reading to that height. The French have another standard, the star candle, burning 154 grains per hour.

Table of Photometric Standards.—The following table gives the relative values of the more important standards of light:

	Violle	Carcel	Star candles	German candles	English candles	Heffner-Alteneck
Violle	1.000	2.08	16.1	16.4	18.5	18.9
Carcel	0.481	1.00	7.75	7.89	8.91	9.08
Star candles	0.062	0.130	1.00	1.02	1.15	1.17
German candles	0.061	0.127	0.984	1.00	1.13	1.15
English candles	0.054	0.112	0.870	0.886	1.00	1.02
Heffner-Alteneck	0.053	0.114	0.853	0.869	0.98	1.00

Shadow Photometer.—If a rod or bar is placed upright, and two lights are placed a few feet apart and a few feet back from it, they will cast two shadows upon an adjacent wall or white paper screen. The lights or one of them are moved back and forth until the shadows are of equal intensity; then the distance of each shadow from the lamp diagonally placed with reference to it must be measured. The illuminating power of the lamps will be in inverse proportion to their distance.

Suppose a lamp which was being tested was 48 inches from the shadow appertaining to it, and the standard candle was 12

inches from the other shadow. Then the illuminating powers of candle to lamp are as $\overline{48}^2 : \overline{12}^2$, or as 16 : 1.

In Fig. 440, E is the lamp under trial with voltmeter V and ammeter A. It is held on an arm carried by the spring clip H. C is

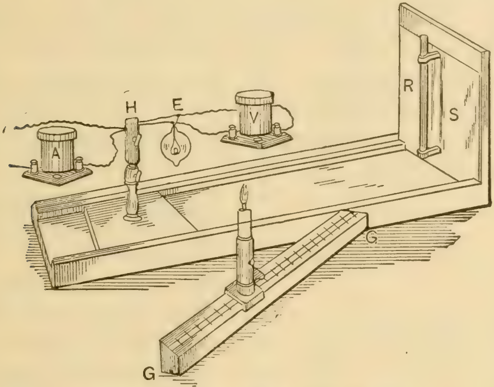


FIG. 440.—SHADOW PHOTOMETER.

the standard candle on a scale G G. R is the rod whose shadows from lamp and candle are seen side by side on the paper screen S.

This principle can be applied roughly in the street or elsewhere

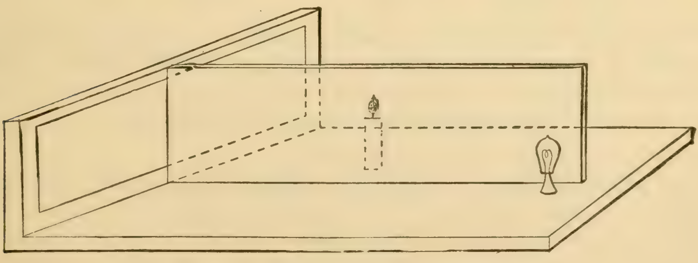


FIG. 441.—BOUGUER'S PHOTOMETER.

by comparing shadows thrown by two lamps, and pacing off or measuring the distances. A gas lamp can thus be compared with an arc lamp with some approach to accuracy.

Bouguer's Photometer.—The cut, Fig. 441, shows another sim-

ple apparatus. The two lights under comparison are placed on opposite sides of an opaque screen, and illuminate a translucent one of paper or ground glass placed at right angles to the separating one. When both halves appear equally illuminated, the distances from lights to screen are measured, and the values are calculated by the law of inverse squares. The observer is stationed on the further side of the translucent screen.

Foucault's Photometer.—This is a modification of the one just described. The opaque screen is moved back until the dark line or band at the junction of it with the translucent screen disappears. The cut, Fig. 442, shows the principle. In this way the comparison of the two divisions of the translucent screen is much facilitated.

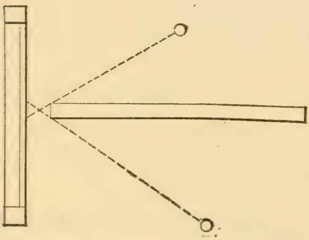


FIG. 442.—FOUCAULT PHOTOMETER.

Direct Photometering of an Arc Lamp is not very satisfactory, on account of its richness in violet rays. The standard against which it is tried gives a light of a far different character. A very simple and practically efficacious instrument for testing the relative qualities of arc lights is the luminometer.

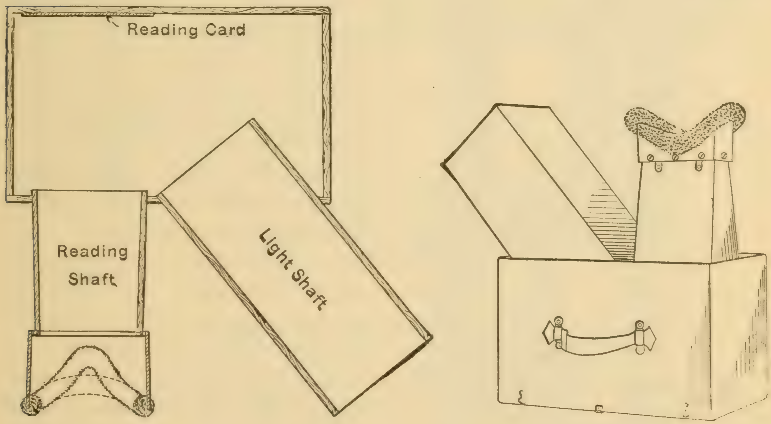
In this instrument the human eye in its every-day action of reading is made the measurer of the light. This is very logical, because the object of artificial light is to enable the eye to see, and the light may be measured by the ability of the eye to see things illuminated by the light examined.

The Luminometer.—It is a box, Figs. 443 and 444, containing a card of printed matter. Two tubes open into it. One receives the light from the lamp. The observer looks into the other, and sees the card illuminated by the light under trial. The light falls on it at such an angle that light is not reflected directly into the observer's eyes. The distance at which the card can be read is called the luminometer distance. The illuminating power is determined by this distance. The test gives the practical power of the light tested.

Two features characterize this instrument. One is its portability. It can be taken anywhere and used in the open street. By using cards printed in various sizes of type, it can be accommodated to different distances. The other feature is its direct appeal to the eye. A light is produced to enable the human eye to see. This instrument tests the power of the light for this purpose.

It is the invention of Mr. W. D'A. Ryan, of the General Electric Company.

Pupillary Photometer.—The pupil of the human eye expands



FIGS. 443 AND 444.--LUMINOMETER.

and contracts virtually under the effect of varying intensity of light. The iris, in other words, acts like a diaphragm of a photographic lens, and affords a larger or smaller opening according to the light acting on the retina of the eye. The pupillary photometer is based on this principle. It measures the diameter of the pupil of the eye when affected by different lights. This gives a coefficient of intensity of the light.

Around the edge of a disk a number of pairs of holes are made near the outer ends of the radii. The holes of the different pairs vary in distance from each other. One pair of holes are sep-

arated by a space of 0.07 inch. These are the closest spaced. The widest spaced are 0.38 inch apart. A second disk is pivoted over the first. It has a radial opening, which exposes one pair of holes at a time. The light to be tested is looked at through a pair of holes. One pair after another is tried, until a pair is found whose edges seem to touch. There is a scale marked on the screen with a value for each pair of holes. It gives the diameter of the pupil which brings the two holes apparently in contact. The reading gives the relative brightness of the light, on the basis of the relative size of the pupil of the eye. The standard light is first looked at, and the holes which seem to touch are found for it. Then the light to be tested is examined, and the corresponding factor found for it also.

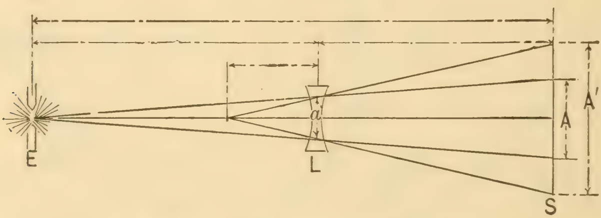


FIG. 445.—DIFFRACTION PHOTOMETER.

Diffractive Photometer.—In testing powerful lights a concave lens is sometimes used to increase the diffraction of the rays and make it possible to use a shorter bar. The cut, Fig. 445, illustrates the principle. The light given by the lamp E is diminished by the lens L in the inverse ratio of the squares of A and A′.

Spherical Candle Power.—The electrician often takes a number of photometric observations at different angles. To do this a standard or rated incandescent lamp is used as a standard. The value of this is known in candles when its voltage or amperage are at a known value. The lamp to be tested is mounted so that it can be rotated horizontally or vertically. A number of observations are taken at angles numerous and diverse enough to represent the surface of a sphere, and the average of the observations gives the spherical candle-power. The lamp is

mounted on a support which can be rotated in all directions, and a number of observations at many angles are taken and averaged. The horizontal candle-power is averaged by rotating the lamp rapidly and photometering it while in motion.

There are various methods of averaging the observations at different angles. A system employed at the Paris Exposition of 1881 consists in dividing the surface of the imaginary sphere into horizontal zones. The candle-power is determined for angles corresponding to the center of each zone. These candle-powers are multiplied by the relative areas of the zones to which they respectively belong. The sum of these products is divided by 4π to get the mean spherical candle-power. The factor 4π is taken as the area of a standard sphere.

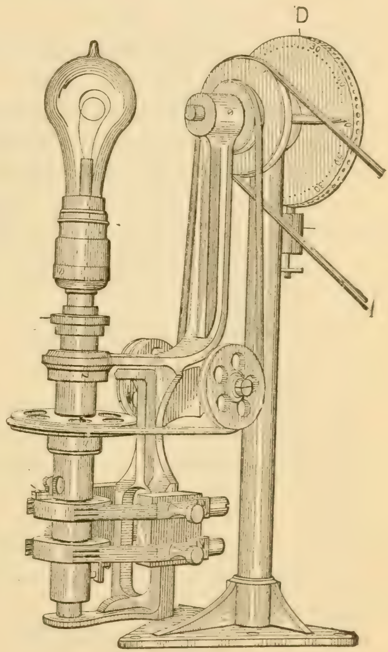


FIG. 446.—APPARATUS FOR SPHERICAL CANDLE-POWER.

The cut, Fig. 446, shows an apparatus for taking spherical candle-power of an incandescent lamp. The lamp is mounted so as to be rotated rapidly by an electric motor. This gives an average illumination all around, and the candle power is determined while it rotates. It is mounted so that it can be inclined at various angles from the vertical while still rotating. Observations of candle-power are taken while it is in various positions, as indicated on the scale D. An average of the observations is taken as giving the candle-power.

If the candle-power is determined at different angles in the

horizontal plane, it is generally enough to determine one set of vertical-angle candle-powers—the candle-powers at various angles on one meridian. The corresponding candle-powers on the remaining meridians may be calculated from the relations of the different candle-powers on the horizontal plane. If the lamp is rotated as described, the average is given directly as far as the different horizontal angles are concerned.

Candle-Powers of Incandescent Lamps.—The horizontal candle-power of an incandescent lamp is its maximum, but the ratio of horizontal to spherical varies greatly according to the shape of the filament. The table gives the mean spherical and mean horizontal intensity of several incandescent lamps.

	Mean Spherical Candle-Power.	Mean Horizontal Candle-Power.
Edison	15.49	18.83
Stanley	13.56	16.54
Woodhouse and Rawson...	15.09	19.11
White	12.44	15.08
Weston	16.27	17.87

The candle-power at different vertical angles varies very greatly. The tip on the top of the bulb diffracts light, and reduces the vertical candle-power at that end, while the base of the lamp reduces it to zero at the other end. It will be sufficient to give a set of candle-powers for an Edison lamp taken at vertical angles of 0°, 30°, 60°, and 90° all around the lamp. 0° gives the horizontal plane.

0°, 16.70; 30°, 15.02; 60°, 9.54; 90°, 3.57; 120°, 8.25; 150°, 14.96; 180°, 16.82; 210°, 14.84; 240°, 9.07; 270°, 0.00; 300°, 9.84; 330°, 15.06.

The Photometry of the Arc Lamp is far from satisfactory. The carbons are never perfectly homogeneous, are almost certain to be a little out of center, and this causes the horizontal candle-powers to vary greatly. After burning a little while, carbons are apt to bend a little, which throws the ends out of line with each other. The candle-power in one direction on the horizontal plane may be twice or three times as great as in the other. The maximum candle-power is found many degrees removed from the

horizontal. This varies far less at different meridians than does the horizontal candle-power.

The variations at vertical angles are very great. A direct-current arc gave the following candle-powers at different vertical angles:

Above the horizontal, 60°, 48; 30°, 110.

At the horizontal, 0°, 208.

Below the horizontal, 10°, 401; 20°, 612; 30°, 871; 40°, 1,000; 50°, 807; 60°, 457; 70°, 188.

As arc lamps are used, the mean spherical candle power is of little importance, and it is not often determined. It is a laborious operation, as the great irregularity of the distribution of light requires a large number of observations at small angular distances from each other. A short road to the result is that proposed at the Paris Electrical Exposition of 1881. The average horizontal candle-power is divided by 2 and added to the maximum candle-power divided by 4. The sum is taken as the spherical candle-power.

Thus a Brush arc lamp gave a mean horizontal candle-power of 909 candle-power; a maximum candle-power of 4651 candles; and a spherical candle-power as calculated, 1776 candles; and spherical candle-power by observation, 1675 candles.

The formula reads thus:

$$S = \frac{H}{2} + \frac{M}{4}$$

in which S is the spherical candle-power, H is the average horizontal candle-power, and M is the maximum candle-power. From a number of observations it is found that the formula gives an error of 1 to 14 per cent.

Mechanical Equivalent of Light.—Light is the action of certain ether waves upon the retina of the eye. If light is decomposed by means of the prism, the visible spectrum will be embraced within relatively narrow limits. The violet end of the spectrum has its color produced by the shortest waves that affect the eye. A musician would say that violet was a very high note, or at the top of the scale. Beyond the violet there are waves which are so short that the eye does not take cognizance of them. These rays act with great energy on chemical agents such as salts

of silver. A photograph can be taken by means of them. If separated from the other rays, they would enable a photograph to be taken in a dark room.

Going to the other end of the spectrum, the red appears due to relatively long waves or high heating power. Below the red is a long stretch of spectrum quite invisible, but producing heat. By a sensitive thermometric apparatus the spectrum can be followed out a long distance below the scale of visibility.

A micron is about one twenty-five-millionth of an inch or one one-millionth of a millimeter. The shortest wave length of visible light is 0.360 micron for normal eyes. Dark red light has a wave length of 0.810 micron, and 1.000 micron is the utmost range of visible light. This is a range of 0.640 micron, within which all visible rays must lie. Above this range is the ray of invisible actinic radiation, "invisible light" it is sometimes paradoxically called, due to the spectrum of radiations less than 0.185 micron long. Below the spectrum we have heat radiations, due to waves less than 30 microns long. Thus without including Hertz waves it appears that in a range of nearly 30 microns only 0.640 micron is visible, or in decimals 0.021 of the entire scale of naturally-produced ether waves.

Light being a physiological effect of a natural cause can hardly be said to possess a mechanical equivalent. Yet if we determined the mechanical equivalent of the entire radiations of a given spectrum, and subtracted therefrom the proportion which was obscure, we would obtain a figure that might be taken as the mechanical equivalent of light. This has been done. The total energy of the rays from a source of light was determined by an air thermometer. The air expanded under the influence of the total heat received. The luminous rays were screened out by a dark solution, such as one of iodine, and the heat imparted by the invisible rays was determined. A thermo-electric pile was employed for this. The experiment by Tumlirz is described in Wiedemann's Annalen.

He found that the light given by the Heffner-Alteneck lamp, which is 0.98 standard candle, was 0.00361 gramme degree C. calorie per second, or 151,500 ergs per second. This corresponds to the energy rate of a current of 0.1226 ampere through a re-

sistance of 1 ohm. By Ohm's law $E = RI$. This gives a voltage of 0.1226 volt. The electric energy is $0.1226 \times 0.1226 = 0.0150$ volt-ampere, or watt.

The pupil of the eye covers a very small portion of the spherical area of illumination. If the eye were 1 meter (39.37 inches) from the light, and if its pupil were 3 millimeters (0.118 inch) diameter, the light it would receive on the above basis would require a year and 89 days to raise 1 gramme (15.403 grains) of water 1° C. or 1.8° F.

If the physiological aspect of the subject is dropped, the above may be taken as of value. It gives with reasonable closeness the mechanical equivalent of rays which affect the human eye.

The mechanical energy expended by a source of light may be divided by the units of light which it gives. The quotient is a practical figure expressing the relative economy of the source of light, and this figure is sometimes incorrectly called the mechanical equivalent of light.

Thus a 16-candle-power kerosene lamp was found to burn oil enough to represent 37 calories per hour per candle. This gives 428.6 meg-ergs per second, a rate of energy equal to 42.8 watts. A gas burner required 68.8 watts per candle-power. An incandescent lamp is generally allowed 3.5 watts per candle-power. The arc lamp may go as low as 0.8 watt.

The light of the spectrum is due to ether waves succeeding each other approximately between 4×10^{14} and 7×10^{14} times per second. In a second they travel about 180,000 miles. If we divide this by the number of waves per second of any given light, we shall obtain as quotient the length of such wave. As, roughly speaking, light travels a little over 10^{11} inches per second, the quotient of $10^{11} \div 10^{14}$ would be one 1/1000 of an inch. On the basis of 4×10^{14} waves per second, such wave would be about 1/4000 inch long.

Watts per Candle-Power in Arc Light.—The watts per candle-power for direct-current arc lamps vary from 0.60 to 1.13 watts; for alternating-current arc lamps, from 1.13 to 1.80 watts. As an interesting example of the practice of some years ago, the Jablochkoff candle may be cited. At 200 candles it used 2.80 watts per candle, and at 500 candles 1.81 watts per candle.

Watts per Candle-Power in Incandescent Lamp.—In incandescent lamps at high efficiency 2.5 watts may be absorbed per candle-power. Lamps run at this efficiency soon break down. A low efficiency is 3.5 watts, when the light given is expensive with regard to the power absorbed. The mean figure of 3 watts to the candle-power represents good average practice.

Quality of Arc Light.—The diagram, Fig. 447, taken from Abney, shows the proportions of the different rays of the spectrum in gas, arc, and sunlight. The curve of gaslight may be taken as practically that of the incandescent carbon-film electric lamp. To obtain a light pleasing to the eye, too much of the light of the

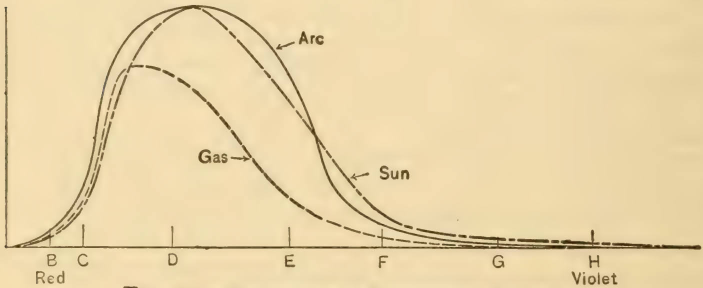


FIG. 447.—QUALITIES OF DIFFERENT LIGHTS.

violet end of the spectrum should not be present. The sun may be taken as giving the mixture which it should be the object of the engineer to imitate in producing artificial light. The arc's light, it will be seen, approaches closely to the composition of the light of the sun.

A convenient way to remember the succession of colors in the spectrum is by the combination *vibgyor*, indicating violet, indigo, blue, green, yellow, orange, red. Lithium chloride gives a brilliant red light when a wire dipped into it is held in an alcohol or Bunsen-burner flame. Copper gives a green, salt a yellow light. The rays of short wave length, such as violet, are not easily produced except when accompanied by other rays. The mixture of light of all colors gives white light. This is what is needed by mankind for illumination.

In photometering arc lamps, as we have seen, values widely differing are found at different vertical angles. These values for a given lamp, with specific carbons, current, and other factors, are reasonably constant. The horizontal angle should make no difference if the lamp works perfectly. But invariably the departure from centering of the arc shifts the hottest point of the carbon to one side, so that in practice a difference may always be anticipated.

Arc lamps have received a sort of trade valuation—that of 2,000 candles. This has long been recognized as grossly inaccurate and in excess of the truth. The so-called 2,000-candle-power lamp is one of standard size using less than 500 watts. The present standard is 10 amperes and 48 volts, or 480 watts. From such a lamp by manipulation at the photometer 1,700 or 1,800 candle-power can be obtained as a maximum. The average maximum candle-power for a direct-current lamp at a vertical angle of 45° is about 1,250 candles.

The alternating-current lamp distributes its light symmetrically above and below the horizontal plane. The direct-current lamp distributes its light principally below the horizontal plane.

There is a distinction between open-arc and inclosed-arc practice. The open-arc lamp works with its carbons much closer together than does the inclosed arc. As we have seen, about 85 per cent of the light comes from the crater in the positive carbons in direct-current lamps. In alternating current, 95 per cent comes from the carbons. The adjustment of the carbons, if varied by the smallest amount, changes the distribution of the light. The arc is about one-eighth inch long. A small fraction of an inch makes a considerable difference in so short a distance.

The inclosed arc is produced between carbons which are considerably farther apart. The slight changes in feed are referable to a longer distance, and hence affect the arc less in proportion than for the shorter-distanced carbons in the open-arc lamp. The carbons in the inclosed arc burn with flat ends. The arc travels about between the disk-shaped ends of the carbons. The arc in open-arc lamps also shifts about, but its movements affect the distribution of the light much more. Figs. 448 and 449 show results from photometry of open-arc and inclosed-arc lamps.

The distances from center of carbon space to the curves give the relative values of the candle-power at different vertical angles.
of the candle-power at different vertical angles.

The long arc diminishes the screening effect of the lower carbon. If carbons are fed close to each other, the lower one will cut off part of the light which would otherwise reach the ground.

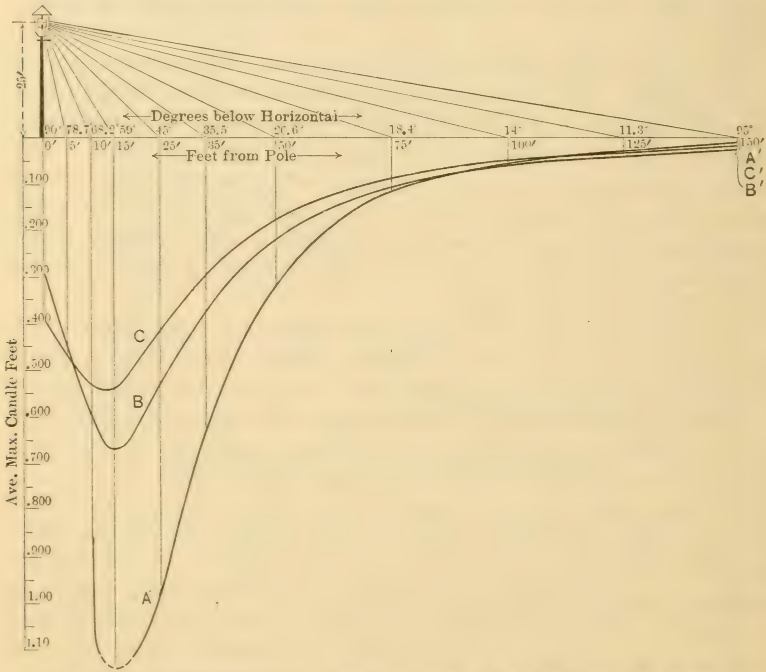


FIG. 448.—DISTRIBUTION OF LIGHT FROM AN ARC LAMP ON POLE.

Distribution of Light from Arc Lamps in Service.—The illustrations, Figs. 448 and 449, show the distribution of light in the vertical plane from arc lamps. The curve A in both diagrams gives the distribution of light from an open-arc lamp using 9.6 amperes of direct current. Of high illuminating power near the lamp, it rapidly drops off. The curve B is that corresponding to the light from an inclosed-arc lamp using 6.6 amperes of direct

current also. The distribution of light is far evener than in the case first cited. The curve C corresponds to the light from an inclosed-arc lamp using 7.5 amperes of alternating current. The diagrams are so fully marked as to be virtually self-explanatory. We are indebted for them to the General Electric Company.

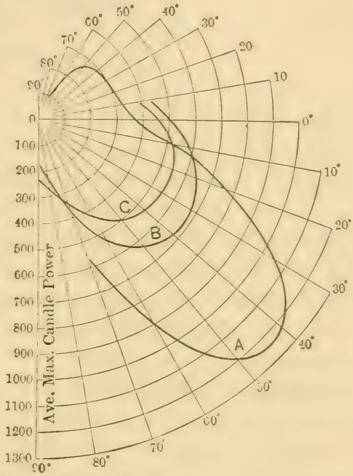


FIG. 449.—DISTRIBUTION OF LIGHT FROM AN ARC LAMP.

Distribution of Light from Incandescent Lamps.—The light given by incandescent lamps in different directions varies greatly. The single-loop filament gives the most irregular distribution, varying from an average for the horizontal plane of 16 candles down to 5.7 candles from the tip. The small quantity of light given from the tip is due largely to the glass tip or point refracting the light in all directions, which falls upon it. A lamp whose filament has two turns in it gives a much evener distribution from 16 candles down to 10 candles.

It is not of great importance to have even distribution of light, because the lamp can be adjusted to give the most favorable aspect to the reader or user of it, and because incandescent lamps are so often put in clusters, which tends to even matters.

CHAPTER XXXIV.

THE ELECTRIC RAILWAY.

The Electric-Car Motor is constructed with a view to protection from mud and water. It is accordingly inclosed in an iron case, and this case is used as part of the field magnet. From its interior the poles project inward, and field coils are placed on these poles. A drum armature revolves inside the case. On the end of the armature shaft a pinion is mounted. This gears into a large gear wheel on the driving axle of the car.

Such is the general outline of the trolley-car motor as now constructed.

Standard Voltage and Allowable Temperature.—The trolley systems have a standard voltage of 500 volts. The motor capacity is rated as horse-power, which refers to the power it can develop without getting overheated. The temperature of 167° F. (93° C.) is considered a sort of standard allowable rise of temperature. Motors are often rated on the power which can be developed continuously for an hour with a rise of temperature of 167° F. (93° C.). This rise is generally based on an atmospheric temperature of 45° F. (7 C.) as a starting point, thus giving the temperature of boiling water as the allowable temperature of a motor.

In practice the motor is cooled to a considerable extent by the motion through the air. It is thought that this is good for about 20° F. (11° C.) reduction from the above figures.

Cause of Motor Heating.—The heating of a motor indicates core loss and copper loss. The first-named source is caused by eddy currents, and varies principally with the voltage.

The Copper Loss is the heating of the wires by the current passing through them. The heating effect of a current varies with the energy rate or with the volt-amperes, or watts.

We have as the formula for watts I E, and by Ohm's law

$$E = R I$$

and substituting for E this value we have

$$\text{Watts} = I E = R I^2.$$

This states that with constant resistance the watts absorbed by a conductor vary with the square of the current, and therefore the heat developed varies with the same.

The copper loss is determined from the current intensity and varies with the square of the current, and for a continuous current the practical determination is easily made by running the motor and ascertaining its heating under different loads. A thermometer gives the temperature. This is very simple; but when varying currents are in question, the difficulty of reaching a conclusion as to the permissible average current is considerable. The heating effect varying with the square of the current, a momentary increase of current produces far more than its direct proportion of heat. Suppose the current doubled for a few seconds. During that period it is developing four times the heat it did at the lower rate.

The heat developed by an irregular current varies with the mean square of the current. The greatest allowable average current is equal to the square root of the mean square of the current. It is estimated that this quantity for ordinary street-car service will be about 35 per cent greater than the average current.

Thus, if a motor could without overheating pass a steady current of 50 amperes, it could pass approximately an average current of 38 amperes under the conditions obtaining in street-car service as assumed under the above estimate.

This would be a most valuable figure, were it not that it applies only to an estimated condition of a particular service. Accuracy can only be reached by a determination of the average current for each specific case. To determine average current, the ammeter should be put in series with a single motor, where the series-parallel system is used. Where this system is in use, the current per motor is generally a good deal in excess of half the total current. The reason is that when the motors are put in series, each one takes the total current.

Determining the Heating of Motors.—This may be done

roughly by the use of thermometers on the outside of the coils. Another more satisfactory way is by determination of resistance before and after a run. The resistance of copper varies as the temperature varies, and from a table of resistance changes due to temperature changes, the heat to which the conductors are subjected can be calculated.

Conditions Causing Heating.—An insulating material which is an especially poor conductor of heat and lack of ventilation of the armature cause high temperature in motor windings.

Horse-Power of Car Motors.—A fair allowance of tractive power for average conditions is about 20 pounds per ton weight on a level, with an addition of 20 pounds for each per cent increase of grade. Within reasonable limits of speed these figures do not change greatly. A spring balance placed as a coupling between a motor car and a trailer would indicate on level ground a pull of about 200 pounds if the trailer weighed 10 tons. Horse-power varies with the product of force by space traversed per second. The horse-power with approximately constant tractive effort would vary approximately with the speed. If the speed of a moving car and its traction in pounds are known, the horse-power can be calculated.

A horse-power is 550 feet per second multiplied by one pound, which is 1,980,000 feet per hour multiplied by one pound. ($1{,}980{,}000 = 550 \times 3{,}600$; $3{,}600 =$ the seconds in one hour.) This can be put thus for a car in motion:

$$\text{Horse-power} = \frac{\text{Feet per hour} \times \text{Traction in pounds}}{1{,}980{,}000}$$

There are 5,280 feet in one mile, therefore

$$\text{Feet per hour} = \text{miles per hour} \times 5{,}280.$$

Substituting this value in the last formula, we have:

$$\text{Horse-power} = \frac{\text{Miles per hour} \times 5{,}280 \times \text{Traction in Pounds}}{1{,}980{,}000}$$

Dividing both numbers by 5,280, we have:

$$\text{Horse-power} = \frac{\text{Miles per hour} \times \text{Traction in pounds}}{375}$$

Suppose a 20-ton car is going up a 2 per cent grade at 16 miles an hour. The traction on the level grade at 20 pounds to the ton

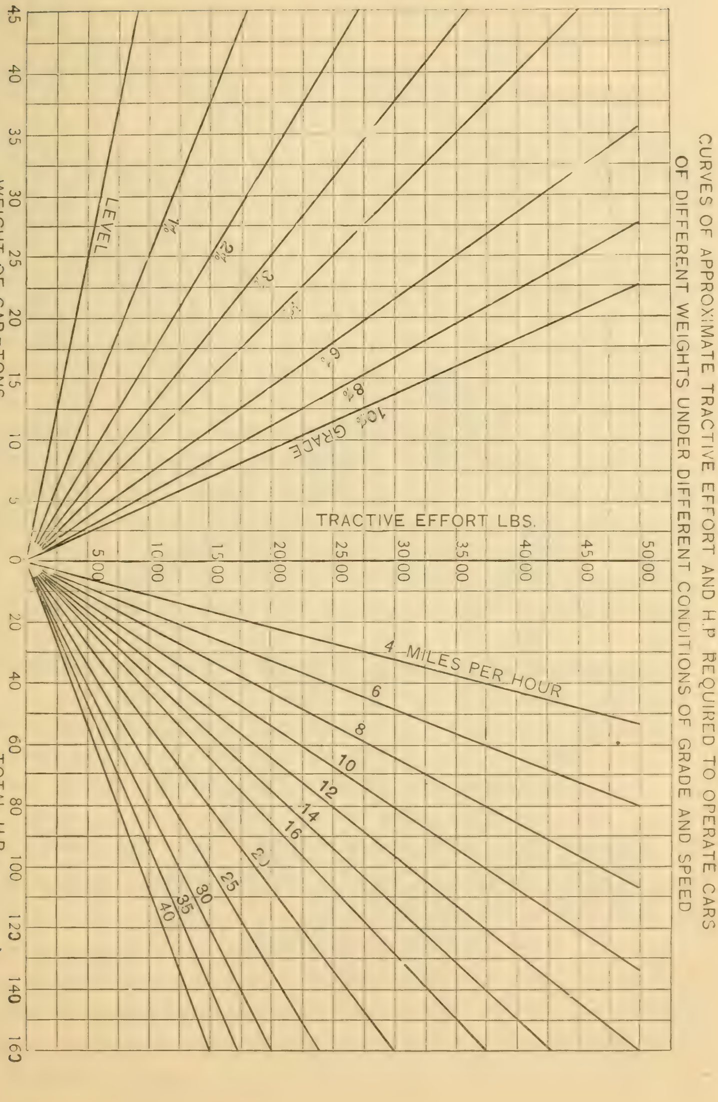


FIG. 450.—TRACTION TABLE.

would be 400 pounds. Allowing 20 pounds more traction per ton per each per cent of grade, the traction on a 2 per cent grade would be 1,200 pounds. The formula is now applicable.

$$\text{Horse-power} = \frac{16 \text{ miles per hour} \times 1{,}200 \text{ pounds traction}}{375}$$

giving 51.2 horse-power.

Traction Table.—The table, Fig. 450, gives traction data. The central column of figures gives the tractive effort. Car weights are given at the bottom on the left. The vertical line rising from any given car weight intersects the lines of grades. If from any such intersection the horizontal line is followed to the right, it will give the tractive effort to move a car of that weight up the grade in question. Thus, a 20-ton car on a 10 per cent grade will require a little over 4,300 pounds traction, or drawbar pull if it were a case of towing.

On the right hand is given horse-power at given traction and speed. Thus, taking any given traction and following out the horizontal line, it intersects different speed lines. If from any intersection the vertical line is followed down to the base, it will give the horse-power. Taking 4,300 pounds traction of the last example at 10 miles an hour, the vertical line from its intersection with the 10-mile-an-hour line leads to about 115 horse-power.

Construction of Electric-Car Motor.—The general features of a standard railway motor may be thus summarized:

There are four field poles projecting radially inward from the iron case, which constitutes in itself a portion of the field magnets corresponding to the yokes. The yoke or case is of steel casting; the projecting poles are of laminated iron or disks. These are fastened together, and are cast into the yoke. The yoke is made in halves, hinged at the side parallel to the car axle, so that the case can be opened like a box. The field is shown in Fig. 451, opened with the poles projecting as described.

The field coils are wound upon molds in a lathe, and are insulated with mica and fuller board. Each coil is solidly made, and slips over a pole piece. Cast brass pieces bolted to the yoke hold each coil in place. Two field coils are on poles in the upper half of the case. Their terminals are soldered to insulated wire

pieces several feet long, to keep them out of the way of the brush holders. The coils in the lower half of the case have metallic terminals.

A slotted drum armature of disk or laminated structure is used. Holes are made through the assemblage of disks to secure ventilation, in order to keep down the temperature. A low temperature conduces not only to higher power capacity, but to efficiency and to security from injury. The winding of the coils is designed to secure ventilation. Three coils are wound together and are insulated in a casing, which is then placed in the slot in the armature. No bending or hammering into place is needed or used.

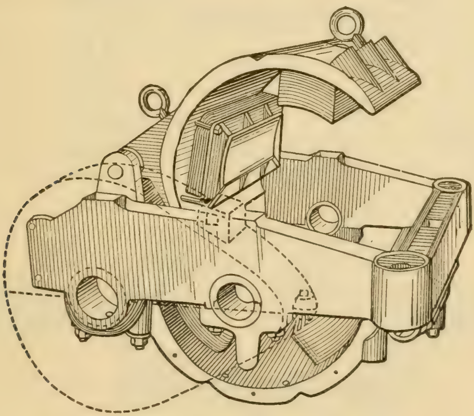


FIG. 451.—CAR MOTOR FIELD OPENED.

Steel binding wires, themselves sunk into grooves running around the armature at right angles to the conductor grooves, hold the armature coils in place. The imbedding of these wires prevents them from cutting if the armature should become so badly displaced as to strike the field poles.

The commutator is of the regular mica-insulated type. The brush holders are fastened to the upper half of the case.

The armature shaft carries a forged steel pinion. This works into a cast-steel gear wheel on the driving axle of the car. Standard gear ratios are 58 to 24, 64 to 18, and 68 to 14. These are

such that the teeth will constantly change in relation, the same teeth coming together but seldom as the gears rotate.

A large air gap is allowed between field poles and armature. This, although disadvantageous from the point of view of the permeance of the magnetic circuit, minimizes the effects if the armature should get out of center. One of such effects is a strong side pull exerted by the nearest pole or poles. If the air gap is

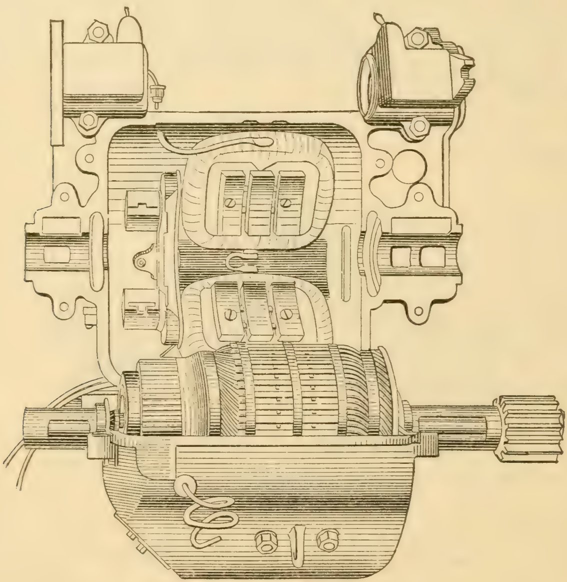


FIG. 452.—CAR MOTOR OPENED.

large, a given displacement, a tenth of an inch for instance, is much less proportionately than it would be with a small air gap. If the air gap were one-tenth of an inch, such displacement might be termed 100 per cent; if the air gap were half an inch, it would be only 20 per cent on the same basis.

A typical car motor with the field opened is shown in Fig. 452.

Switch Boxes and Circuit Breaker.—The current from the trolley pole connection goes first to a switch placed over the plat-

form on the under side of the projecting roof or canopy. There is another of these switches at the other end of the car, and the two are in series with each other. The current enters by one switch, goes through it, and a conducting wire leads to the other switch, and from it the current is led to a fuse box or mechanical circuit breaker. The two switches are called canopy switches, main motor switches, auxiliary or overhead switches. There is generally an electro-magnet in the switch box, which prevents any arc from forming when the switch is opened. The magnet repels the arc, and puts it out as a draft of air puts out a candle, although on widely different principles. It is called a blow-out magnet or magnet coil.

Lightning Arresters.—After passing the circuit breaker, or else the fuse box if such is used, the lightning arrester is reached.

The old lightning arrester consisted of two plates with saw teeth secured so that tooth faced tooth at a small distance. The circuit to be protected has one of its leads attached to one of the plates, and thence goes on its regular course. The other plate is grounded. If lightning enters the system, it easily breaks across the air gap and goes to earth before it reaches the controller, dynamo or other appliances. Lightning has such high potential that ohmic resistance means little to it. But it is of oscillatory character, and a relatively slight inductance will resist its passage strongly. In the course of the circuit as it leaves the lightning arrester a choke coil is placed. This is of slight ohmic resistance, and has a negligible effect on the working current of the system. When lightning enters the circuit, this acts by its inductance to hold it back and to force it to the earth over the gap in the lightning arrester.

Another lightning arrester has two carbon terminals with their ends close together but not touching. The lightning gap is at this point. If lightning strikes the circuit, it springs across the gap and goes to the earth. A coil of wire surrounds the upper end of one of the carbons and extends some distance above it. Within the coil is an armature lying loosely in it. If the armature is raised, the circuit is broken. If the main current follows the course of the lightning, it excites the coil, and the armature springs up. This breaks the circuit, and the arc is destroyed, and

the armature dropping back to its place, the current goes on its regular course. Other lightning arresters are described elsewhere.

Controllers.—The speed of rotation of a street-car motor and coincidently the speed of the car is regulated by giving it more or less power. The volts of potential difference which produce a current through the car connections and wiring are constant as near as may be. There are in modern practice always two or four motors in a car. For low power the voltage which acts upon each motor or pair of motors is reduced to less than half that of the circuit. For high power each motor or pair of motors is given the entire voltage of the circuit.

There are several controllers in use, the Westinghouse and the General Electric Company's being very extensively employed. The general principle is the following:

A vertical shaft is mounted in a case, generally placed against the dashboard of the car. The case is of sheet iron, approximately semi-cylindrical in shape, with a door which opens its entire height. The shaft is square on top, and a crank handle fits on the square end. Upon the shaft are mounted a number of horizontal cams. In a typical controller there are eleven. They are insulated from the shaft, and are connected together in groups or pairs. The shaft is never turned through a full circle. The cams are of such shape that their working or contact faces are arcs of circles, concentric with the center of the shaft. Some of the arcs are so long that their angular scope is equal to the extreme range of motion of the shaft. Thus, if the shaft moves through 200°, the largest cams would include 200° in their arc. Other cams are very short. They are distributed as regards their working surfaces or contact arcs over the whole range of the angular movement of the shaft. They are secured to the shaft at even distances apart vertically.

By the side of the cam shaft is a series of contact fingers. These are exactly similar one to the other, and arranged vertically and spaced so that there is one finger for each cam. If the shaft is turned to the extreme right, no finger will touch a cam. If turned to the left, the fingers will make contacts. The order of the contacts and the duration of each one depends upon the arrangement of the cams and on their extent of contact surface

or arc. If the cam surface is long enough, the finger will, once it is brought in contact with it, remain in contact for the full swing of the handle. If the cam surface is short, its finger may come in contact with it for a short period and then leave it. The construction of a controller is shown in Fig. 453.

Controller Points.—On the plate which covers the top of the controller case are cast a series of short radial bars or "points," distributed on the arc of a circle concentric with the shaft and cams. Each point indicates a position of the handle. A horizontal wheel is fastened to the shaft immediately below the cover. This has rounded notches in its edge, one for each of the points. A sort of pawl drops into these notches as the wheel is rotated by the handle. The notch and pawl fix the shaft in place, and also disclose to the motorman that a point is reached. If he counts the notches, he will know where his handle is without looking at the points. A qualified motorman need never take his eyes off the road in front. If in doubt as to what point the handle is on, he can turn his handle clear back to the starting point and then return it, counting the notches one by one as he passes them until the desired one is reached. It is not a matter of indifference which points are used; there are preferred driving points which should always be used.

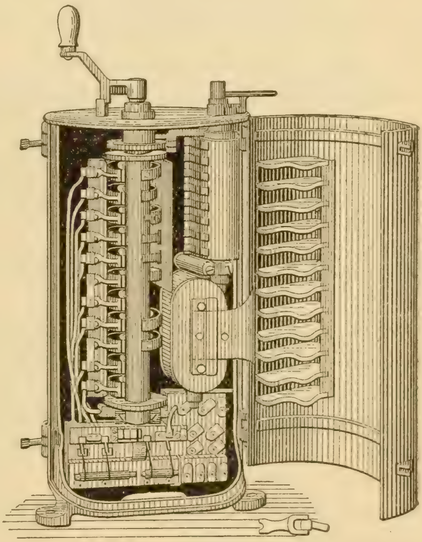


FIG. 453.—TROLLEY CAR CONTROLLER.

Driving Points.—Some points indicate a maximum of resistance in series with the motors. Other points indicate less resistance in series, and there are two or three points which indi-

cate no resistance in series. The general law for the concentration of resistance in machines absorbing energy applies here. The points indicating no resistance are the ones on which the car should be driven. The energy is not wasted in external resistance as it is on the other points. The driving points are cast longer than the others, so as to be clearly indicated to the motorman.

Series = Parallel Controller.—A large variety of controllers of this type are made, adapted for different-sized cars and motors. Naturally, a high-powered car needs more regulating contacts than does a low-powered one.

The term series-parallel indicates that the two motors on a car are operated sometimes in series and sometimes in parallel. This gives two speeds. Intermediate speeds are produced by a set of changes, each one involving a definite step. There is no gradual transition, but a step-by-step progress from low to high speed.

A nine-point controller controls by the following combinations:

When the handle is turned to the first point, it brings into a series of three a resistance and the two motors, one behind the other. The current flows through the resistance, which cuts it down wastefully. Then it goes through one motor, and it is still further cut down, but here not wastefully, and then goes through the other motor, and then to the ground. This connection gives the least energy to the motors that is possible as the connections are arranged.

On moving the handle to the second point, a portion of the resistance is cut out; on moving it to the third point, fourth point, and fifth point, resistance is cut out each time, the motors remaining in series. As the system is run on constant potential, the movements described have increased the current given to the motors, and therefore have increased the power developed by them, and the car under equal conditions increases its speed.

At the fifth point all the resistance is cut out, and the motors are left in series. This is the first running point, as there is no wasteful resistance in series with the motors. The rule that resistance should be concentrated in the motor applies here.

The handle now swings through a transition stage in which (a) the motors again have resistance in series with them; (b) one is cut out, the other having the same resistance in series with it; c the same as b; and the sixth notch is reached. There are no notches for positions a, b, and c; the handle swings by them to the sixth notch, at which most of the resistance is in series, and the two motors are in parallel. This gives more power. The seventh notch cuts out more resistance, the eighth still more, and at the ninth notch cuts out all the resistance and the

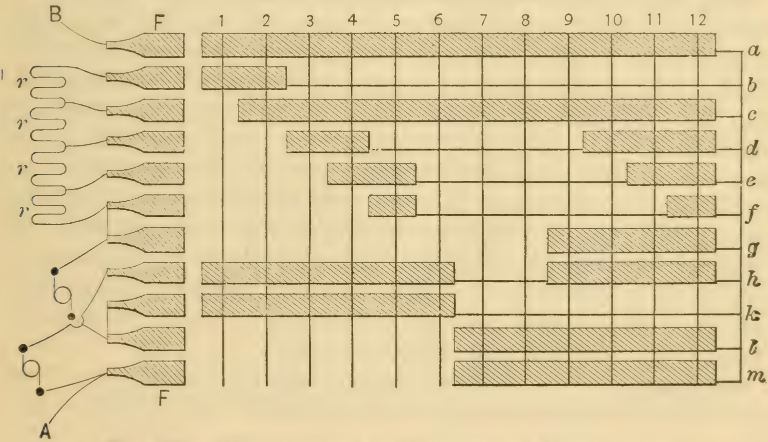


FIG. 453a.—DEVELOPMENT ON CONTROLLER CONNECTIONS.

motors are left in parallel, with the full potential and maximum current acting on them.

The cut, Fig. 453a, shows the development of this controller. The cam faces are supposed to be straightened, and the successive points and the connections for each are indicated. The fingers only make contacts when over the cams. Thus at point 3 and at all subsequent points finger No. 2 is cut off. It only makes contact at points 1 and 2. The cam faces are connected with each other, as indicated by the lines. If the description is followed with constant reference to the cut, the operation will be clear.

There are other arrangements of controller. In some the controller throws a shunt in parallel with the motor fields, thus in-

creasing the speed, the armature taking a still greater current. For high-power motors more points may be given, sometimes as many as thirteen, with the seventh and thirteenth as running points.

Hot Resistance.—If a car is run upon the wrong point the resistance is heated, and a hot resistance indicates wasteful running. A car should be run on the driving points as much as possible, except when it is allowed to coast or drift with all power off.

Blow-Out Magnet.—In the controller case is an electro-magnet whose function is to blow out arcs. As the fingers slip from cam to cam, there is constant danger that arcs will form. The electro-magnet has hinged to one pole a plate of metal, which shuts over the cam shaft and contact fingers like a door, and forms a prolongation or extension of one of its poles. On the inside face are secured a number of blocks of insulating material, corresponding to the spaces between the successive cams. These go into the gaps, and separate each cam with its finger from its neighbor. In the cut, Fig. 453, already referred to, the hinged pole piece is shown swung back, and the asbestos composition insulators are shown projecting from it. The magnetic field extinguishes arcs as fast as they form.

Reverser.—To the right of the cam shaft is a reverser. This operates by reversing the relations of the field and armature connections.

Board and Cut-Outs.—In the bottom of the case is a board, to which the wires from the motors and resistances are connected, as directed in the wiring plan, which the electric manufacturing company supplies. Two knife cut-out switches are here. They have wooden handles, and are numbered 1 and 2. Each one cuts out or in its own motor, according to the number inscribed upon it.

Rheostat Controller.—In this system the changes in current are brought about by changing the resistance in series with the motor or motors. Some resistance is always in series, absorbing energy, except when the car is running at full speed in the rheostat system. This involves waste of energy. The system is out of date.

Motorman's Duties.—Various directions are given for running trolley cars. Several books are published devoted to the motorman's work. Generally, more than one car is operated on a line, and it is fair to say that on all small roads where much business is done a broken-down car will be pushed to the car stable by the next car. General directions for making repairs can be given, but cars differ from one another in their electrical equipment. An electrician in charge of the repairs of cars of a road will have to study their special machinery, and especially the connections used in the cars whose repairs come under his charge. The motorman will only be expected to make the simpler kind of repairs, and may be forbidden to do even that much. Outside of this function, the motorman has very specific duties to perform in running his car properly. It is stated by one author that by actual trial he found one competent motorman ran his car with one-half the power which an incompetent one required.

Economical Running.—It is wasteful of energy to turn power on suddenly. A jerk involves waste of energy, and shakes the whole structure of the car. The power can often be shut off on slight down grades. When the track is obstructed, instead of running up to the obstacle under power and then putting on the brake, the power may be shut off a considerable distance before the obstacle is reached, and a comparatively slight application of the brakes will suffice to stop or slacken the speed of the car as required.

Excessive Use of the Brake is hard on the brake shoes and wheels. If the wheels are completely arrested, so that they slide on the track, it is apt to wear flat places on them. They then need grinding or turning to restore their circular contour. If a wagon is on the track, the car can be slowed by turning off the power while it is still a good distance away, and the wagon may turn out while the car is still coasting. Waste of energy would result from running up to the wagon under power and suddenly turning off the power and putting on the brake at the last minute.

Bad running exhausts the motorman also. The excessive use of the brake is hard work in the fullest sense of the term.

Flat Wheels.—This term is applied to wheels which have had flat places worn upon them. They make a most disagreeable noise

when the car is running, and expense is involved in grinding or turning them to shape.

Sliding Wheels.—Wheels caused to slide by excessive braking do not stop a car as quickly as wheels which turn so as to constantly present a new surface to the rail. If held so that they cannot turn, the spot in contact wears smooth and slides along with less friction than in the other case.

Skidding Wheels.—If wheels turn without moving the car, use a little sand. Turn the power off, and then slowly on again to the last notch.

If wheels slide on slippery rails, when the brakes are put on, do not apply sand. First throw off the brake, start the sand, and then apply the brakes again.

Reversing.—Never reverse the car until the controller handle is in the off position. The car should first be brought to a stop, the reversing lever turned, and then power should be slowly given. The trolley pole should always be shifted, except for very short distances.

Leaving the Car.—If the motorman leaves the car, he should turn the controller completely off and take the handle with him, otherwise some unauthorized person may interfere, and turn on the power.

Bad Ground.—If the rails are dusty, the car may refuse to start because it makes a very poor ground. Rocking the car by swaying and almost jumping on the platform may give a ground to a motionless car which has refused to start. The rail may be cleaned of dust a short distance from one of the wheels, and a ground can be made by touching a bar of metal or a heavy copper wire to the clean spot on the rail and to the tread of the wheel. The car will then start. Pouring water on the track may be enough to form a ground. If the ground is made with a wire or bar as described, the rail must first be touched, and then the wheel. The connection must be firmly held in place, or a shock will result. The motorman can shut off the power an instant to permit the bar or wire to be removed. The use of a thick glove, cap, or piece of heavy cloth for holding the connecting piece is advisable or imperative.

Refusing to Start.—If a car refuses to start with a good

ground, it may indicate that the rail bonds are gone. The rails can be connected electrically with a piece of wire attached in any way that seems best. Even a few nails may be driven between the ends of two rails to give some attempt at a connection.

The lightning arrester may be a source of trouble. If dirt gets into it, it may establish a ground, and so short-circuit all the car connections between it and the motors. This may be of such low resistance as to melt the fuse. If cleaning the arrester is not possible, it may be disconnected, or its ground wire may be removed or disconnected. A lightning arrester making ground will blow out the fuse when the controller handle is in the off position. This is one way of recognizing it.

Fuses.—If the fuse blows when the car starts, it may be due to so great a load that the armature turns abnormally slow, and generates insufficient counter electromotive force. If the brakes are set, or if a quantity of dirt has wedged in between brake shoe and wheel, the load on the motors may be increased thereby, so as to burn out the fuse.

Another cause for a fuse blowing out is the grounding of the field coil of a motor. The cure is to cut out the motor. Short-circuiting of field or armature will do the same. Loose or bad contacts at the ends of the fuse may help to blow it out. The contact pieces at the ends of fuses should be bright and clean, as should the surfaces to which they are secured. Sandpapering or scraping may be resorted to if necessary. Screws holding fuses should be screwed down hard, and should be watched if they are liable to become loose.

Never put in two fuses in place of one or a fuse heavier than the standard, as it might result in a burned-out armature or injury of wires or other connections from overheating.

Examining Connections.—If electrical connections have to be examined, tightened up, or disconnected, either pull down the trolley pole and tie it down, or open the main circuit switch under the platform roof or canopy. Take no risks with a live circuit.

The lamp circuit may be used to give a clew to electrical troubles. If the lamps light, then the current is on the line and the car has a ground connection. It may be only enough for a small current. While the lamps are burning, turn on the con-

troller. If the lamps are dimmed or go out, it indicates a poor ground. There is a possibility of running the car ahead slowly and picking up a good ground again.

Controller Troubles.—Sometimes the car will run with one controller and imperfectly or not at all with the other. A burn-out, a broken or loose connection, a bent contact finger, may be the trouble, or the motor cut-outs may have dropped out of their contacts.

Broken=Down Controller.—If a controller breaks down and the cause is not obvious nor easily removed, run with the other commutator. The car must be run by signal from the front platform in this case, the conductor remaining in front to watch the track.

Motor Troubles may be due to the causes which affect other motors, but greater in degree, because of the conditions under which railroad car motors have to operate. The carbon brushes may not play freely, the commutator may wear uneven or have a high bar, the carbon brushes may even be burnt into the holders from excessive current. There is every chance for dirt and oil to accumulate on the commutator surface. Sparking on the commutator when the motor is running may be due to one of these causes. Absolute flaming on the commutator indicates a broken, short-circuited, or wrongly-connected coil. Such troubles should be found out before the car goes into service.

In the bottom of the controller case are two cut-outs, marked motor 1 and motor 2 or equivalently. If a motor is in trouble, cut it out with its own cut-out and run carefully with one motor. Start the car very slowly and gradually under such conditions. On a steep grade it would be well not to stop at all. A short, steep grade should in such case be taken on the run. Avoid using sand. The point to be remembered with a single motor is to avoid running it slowly with the controller turned to high power.

Emergency Stop.—If the brakes refuse to work, emergency methods must be resorted to. They should be avoided if possible. There are two.

Throw off the power at the controller, reverse the reversing lever, and turn the controller to first or second notch. This method is quick, but is more of a strain on the machinery than the following.

Throw off the power at the controller, open main-circuit switch, reverse the reversing lever, and turn the controller handle to the last notch.

Jerking Car.—If a car jerks or bucks, it may be due to water and mud which has reached the commutator, a bit of wire may have got into the motor case and have short-circuited the commutator bars, or other short circuit may have occurred. The motor in trouble may be detected by the smell due to overheated insulation. Cut it out at once and run with one motor.

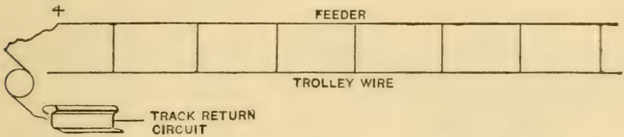


FIG. 454.—FEEDER CONNECTION FOR ELECTRIC RAILWAY.

Car Heating.—Many uses have been found for electric heating, but the expense has restricted its use greatly, and its principal application is in trolley cars. For a car with twelve windows, from 2000 to 3000 watts are needed to supply the heaters, or about 4 horse-power. A car stove burns about 33 pounds of coal per day, and the expense of a day's heating with allowance for repairs to stoves, removal of ashes, and every incidental expense, was calculated at 19¼ cents a day, with coal at $2 a ton. The expense of electric heating varies from 0.36 cent to 2.41 cents per hour. The showing is so favorable only because the electric heating system has comparatively few repairs. The heaters are not removed in summer, and there is little in the way of replacement needed. The fuel cost for a stove may be only 1½ cents for a

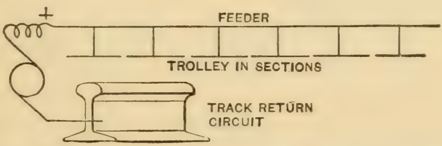


FIG. 455.—FEEDER CONNECTION FOR ELECTRIC RAILWAY.

whole day; the principal expense is in the labor and repair items.

Electric Radiators are simply resistance coils of iron wire sometimes protected by asbestos or equivalent coating. They are placed under the seats, and therefore take no room in the car; a stove sometimes takes the room of one passenger. In a crowded system the conductor may have to neglect a coal stove, and the

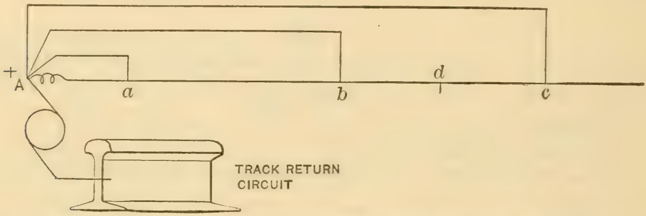


FIG. 456.—SEPARATE FEEDER SYSTEM FOR ELECTRIC RAILWAY.

passengers may interfere with his giving it proper attention. In such cases electric heaters are especially advantageous.

Power Circuit and Feeders.—There are various ways of arranging trolley-line circuits. The simplest consists of a single

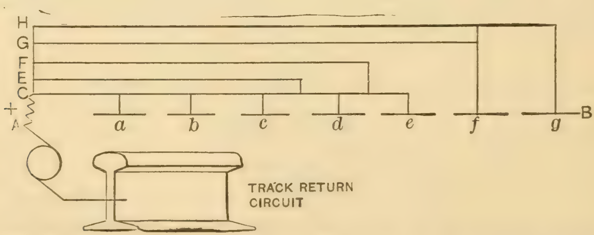


FIG. 457.—INTERCONNECTING FEEDER SYSTEM ON ELECTRIC RAILWAY.

wire with the rails as a return. Sometimes feeders are used to maintain the pressure.

One of the oldest ways of using a feeder is to run it along parallel with the trolley wire, and connect from it at intervals to the latter. This is an imperfect system. Nothing is gained by it over the results which a single trolley wire of cross section equal to that of the two wires would give. A variation on this system is

to divide the trolley wire into sections, each corresponding in length to the distance between feed-wire connections. This makes it possible to cut out any section of the road, which might be useful in some cases of accident. These systems are shown in the cuts, Figs. 454 and 455.

A true feeder's action would consist in keeping a definite potential on a distant point of a line. The trouble is that if a feeder is drawn upon for current, its drop increases, and it fails to some extent in its function. An active feeder must act imperfectly. The following systems try to bring feeder action more into play. In Fig. 456 is shown a road supplied with current as usual through its wire, and with several feeders carried directly from the station and connecting at distant parts of the line. The trolley wire may be divided into sections, and subsidiary feeders may be introduced. By interconnecting feeders the system shown in Fig. 457 may be employed.

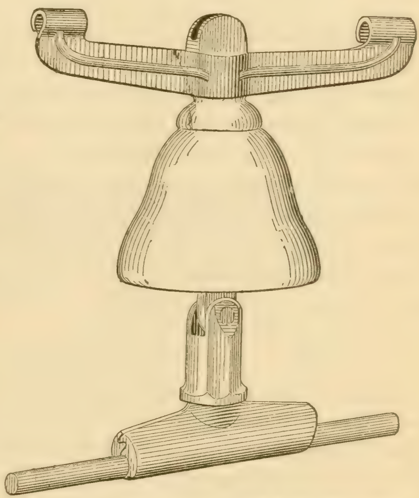


FIG. 458.—TROLLEY WIRE INSULATOR.

Insulators.—These are of the most varied type in the great variety of electric railway work now carried out. Fig. 458 shows an insulator for carrying the trolley wire. It crosses the bottom of the insulator, and the weight is taken by a suspension wire from which the insulator is suspended by the double hook on its top. At the center of the top is a slot through which the suspension wire passes.

CHAPTER XXXV.

ELECTRICAL MEASURING INSTRUMENTS.

The Galvanometer is an instrument for indicating the passage of a current. If used only as an indicator, it is more properly called a galvanoscope. Usually the first name is employed.

Under Ampere's law we have seen the law of the deflection of a needle by a current illustrated. If a common pocket compass with good enough pivot and bearing is held above a conductor through which a current is passing, the needle will be deflected more or less according to the strength of the current. The frictional resistance may be great enough to hold the needle immovable unless a strong current is flowing. Such a compass would constitute a galvanoscope.

To increase its sensitiveness, two things can be done. The delicacy of pivoting can be increased. For extreme sensitiveness the magnetized needle can be hung at the end of a filament of silk instead of being poised on a pivot. To increase the action of the current, the conductor can be bent into circular or other closed curve, and go completely around the needle once or many times. A coil of wire of hundreds of turns may surround the needle. Proximity increases the action. The coil may be so close to the needle as to just leave it room to turn in.

A galvanometer as usually constructed consists of a magnetic needle and a coil of wire surrounding it.

Simple Galvanometer.—The simple form of galvanometer called originally a multiplier is shown in the cut, Fig. 459. A coil of wire wound upon a wooden or pasteboard spool or bobbin surrounds a magnetic needle. The instrument must be placed so that the coil will lie in the magnetic meridian or nearly north and south. The magnet will then lie in the coil in the position shown. When a current is passed through the coil, the needle will

be more or less deflected. On such lines as this many galvanometers of widely varying sensitiveness are constructed.

The needle as shown in this connection has an axis fastened to it. This may be prolonged upward through the coil, and have an index fastened upon it. Then the first movements can be seen. Otherwise they would escape notice because the needle is hidden by the coil.

The needle may be above the coil, when it will move in directions the reverse of those which it would have if within the coil, as shown in the cut.

Astatic Galvanometer.—Sometimes two needles are used fastened to a central axis, with north and south poles opposed. This construction almost destroys the polarity of the two, and would

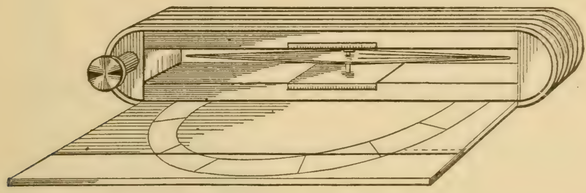


FIG. 459.—SIMPLE GALVANOMETER.

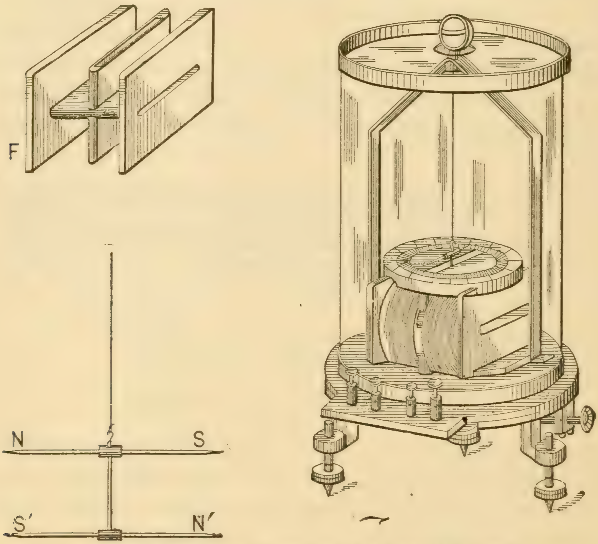
completely were it possible to have them of equal strength. If one magnet is within the coil, and the other with reversed pole is above or below the coil, the deflective action on both will be the same. This is because the poles are reversed.

The cuts, Figs. 460 to 462, show an astatic galvanometer. On a frame F is wound a double coil of wire, whose turns lie in a vertical plane. The astatic needles are shown below the frame, their north and south poles being indicated by N N and S S. The whole arrangement as set up is shown on the right. A glass shade cuts off all air drafts, so as to prevent irregular movements.

Fiber Suspension.—For sensitive galvanometers a thread or fiber is used to suspend the needle. It may be a fine thread of silk. It is sometimes a thread of silica. This is made by melting a piece of quartz, and drawing from it a fine thread on the principle of spinning glass. Sometimes the point of an arrow is

touched to the melted quartz and shot from a bow, drawing out a thread of quartz which is so fine as to be almost or quite invisible.

Reflecting Galvanometer.—The sensitiveness of a galvanometer could be increased by increasing the length of the index. The weight of the index might be a factor which would impair its sensitiveness, and it would be affected by drafts of air unless inclosed. An index four or five feet long would be impracticable.



FIGS. 460 TO 462.—ASTATIC GALVANOMETER.

But a weightless index of any length can be provided by using a parallel beam of light.

A concave mirror will reflect a beam of light, and will produce a focal image of the source of light at a distance from itself determined by the relation of the distance L *o* to the degree of concavity or radius of curvature of the mirror. The conditions are shown in Fig. 463. *s s* is the mirror, L the source of light, and Q the reflected image thrown upon a screen or scale *m m*. The ray Q *o* is the weightless index referred to above. In the reflecting galvanometer the mirror is attached to the magnetic needle indi-

cated by N S in the diagram. The center of the mirror lies in the line of the suspending fiber. The distance Q o may be as great

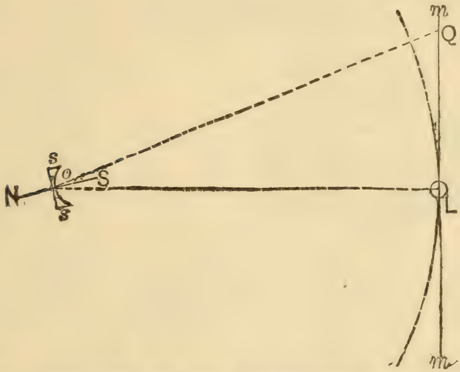


FIG. 463.—PRINCIPLE OF THE REFLECTING GALVANOMETER.

as desired; the longer it is, the more sensitive will the instrument be.

Arrangement of Reflecting Galvanometer.—The diagram, Fig. 464, shows a lamp in a case, with an aperture m m out of which

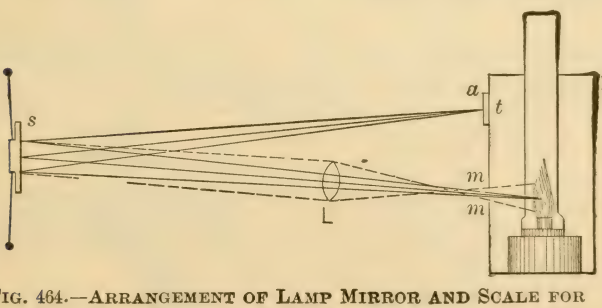


FIG. 464.—ARRANGEMENT OF LAMP MIRROR AND SCALE FOR REFLECTING GALVANOMETER.

a beam of its light emerges. At s is the mirror attached to a galvanometer needle. The latter with all other detail is omitted from the diagram to avoid complication. At t is a long scale

The light which falls upon the concave mirror at *s* is reflected

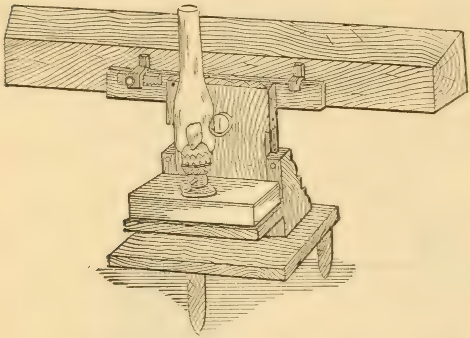


FIG. 465.—ARRANGEMENT OF LAMP SCREEN AND SCALE FOR REFLECTING GALVANOMETER.

upon the scale, and a focal image of the aperture *m m* is produced upon the scale. The aperture *m m* may have a vertical wire across its center, which will appear as a dark line across the spot of light upon the screen and will serve as the index.

In modern practice an incandescent electric lamp is often used instead of the oil lamp. In such a case the lamp is so placed with reference to the focal length of the mirror that its incandescent filament is projected upon the screen, and this image serves as the index.

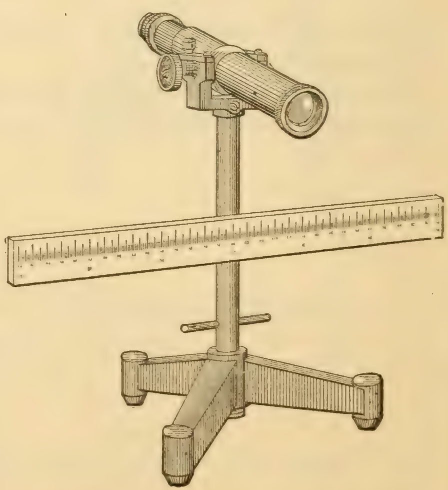


FIG. 466.—TELESCOPE AND SCALE FOR PLANE MIRROR REFLECTING GALVANOMETER.

Referring again to the diagram, Fig. 463, it will be understood that if the mirror S turns left-handedly, the object reflected to and produced upon the scale *t* will move toward the top of the page as shown by the dotted line *Q o*. The reverse will occur for a swinging of the mirror in the opposite direction.

In the same cut a lens is shown in front of the lamp. By using this lens a plane mirror at S may be used instead of the concave one, and the dotted lines indicate the direction of the rays of light when such lens is used.

The next cut, Fig. 465, shows how the oil lamp is placed below the scale and screened from the observer who is in front of it. The aperture through which the rays pass is seen. A vertical wire is secured across it.

Translucent Scale.—The diagrams have illustrated the use of an opaque scale which the observer looks at directly. Sometimes a translucent scale is used, the observer being back of it and watching the index mark through it

Plane Mirror Reflecting Galvanometer.—Another arrangement of the reflecting galvanometer depends upon simple reflection of the scale in a plane mirror attached to the galvanometer needle. The cut, Fig. 466, shows a telescope mounted on a standard with a scale below it. The observer looks directly at the galvanometer mirror and sees reflected in it a portion of the scale. This gives the reading of the instrument. A cross wire, cocoon fiber, or equivalent may cross the mirror or be contained within the telescope, in order to give a line to fix exactly the scale division.

The Thomson or Kelvin Galvanometer.—The characteristics of this instrument are the extreme lightness and small size of the moving parts, which are the needle or needles and a mirror, generally concave. The coil of wire is of rather large diameter as referred to the length of the needle. As used, the deflections of the needle are so small that the current is sensibly proportional to the deflections. It is constructed dead-beat, astatic, or according to any other requirement.

In one type of instrument four magnetic needles 0.015 inch long are cemented to the mirror. The latter is 0.024 inch diameter, the total weight of mirror and needles being 1 grain. The object of having several needles is to get the maximum of magnetization with the smallest weight. This reduces momentum and makes the combination more dead-beat.

The mirror and needles are suspended by a cocoon fiber, unspun silk, and of extreme thinness. The mirror hangs in the center of a vertical ring of brass with closed back, and the front covered

with a pane of glass. The coil surrounds the ring. A rod rises from the ring and carries a curved regulating magnet.

Regulation of Sensibility.—The regulating magnet is turned with its north pole to the south. This counteracts to a certain extent the terrestrial magnetism. It is moved up and down until its action on the needles nearly deprives them of directive force. This is taken as the working position for sensitive work.

An astatic galvanometer is made on the same lines. Two coils wound in opposite senses are employed, one above the other. One acts on one needle and the other on the second needle, whose poles are reversed. The coils are each divided into two parts, so that there are really four coils. The connections are arranged so that the coils can be connected in various ways.

In some very accurate observations the scale is placed 20 feet from the mirror of the galvanometer. This is equal in sensitiveness to an index 40 feet long.

A small form of the Thomson or Kelvin galvanometer is shown in Fig. 467.

The Ballistic Galvanometer is used to measure the quantity of electricity in an instantaneous discharge. In use the discharge is passed through its coils, and the extreme deflection of the galvanometer is noted.

Various types can be employed. Ayrton and Perry have thus modified the Thomson galvanometer for ballistic work. Forty little magnetic needles of different lengths are, with the aid of segments of a hollow lead sphere, mounted as two spheres. The spheres are joined by a rigid rod astatically, or with the magnet poles pointing in opposite directions. The combination is suspended in place of the usual mirror and needles by a fiber. The galvanometer is very sensitive, and the air offers little resistance. It is corrected as follows: Call a' the first throw and a'' the second throw on the same side of the zero mark. The arc a, which would have been attained by the first throw without the resistance of the air, would be expressed by the formula:

$$a = a' + \frac{a' - a''}{4}$$

The extreme limit of an oscillation is called its elongation or instantaneous deflection.

The Deprez-D'Arsonval Galvanometer is much used for ballistic work. The cut, Fig. 468, shows the construction of a simple form.

A strong horseshoe permanent magnet is mounted on a baseboard, its poles projecting directly upward. A rectangular coil of No. 40 silk-covered copper wire is the moving element. This is held symmetrically between the poles of the magnet. The magnet in the instrument we are describing is 7 inches high, and

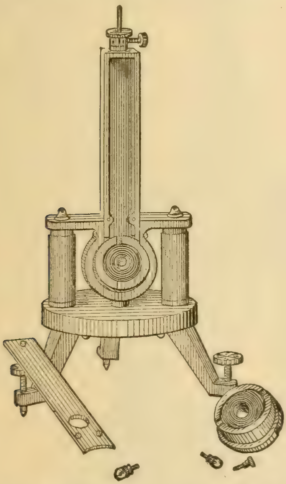


FIG. 467.—SIR WILLIAM THOMSON'S OR KELVIN REFLECTING GALVANOMETER.

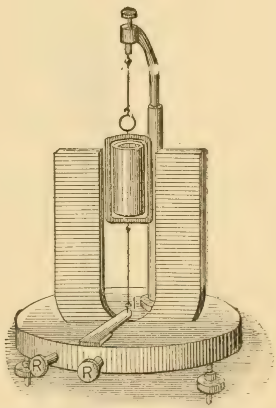


FIG. 468.—DEPREZ-D'ARSONVAL GALVANOMETER. ORIGINAL FORM.

is formed of three magnets each ¼ inch thick and bolted together. The coil of wire is 2½ inches long internally and 1¼ inches in internal width. Within the coil a hollow soft-iron cylinder is supported by an arm projecting from a standard at the back of the baseboard. The cylinder is a fraction of an inch smaller than the coil in all directions, so as to fit within it without touching it. Its sides are about 3-32 inch thick. The coil is suspended by a hard-drawn silver wire No. 32 or 0.008 inch diameter. A similar wire connects the center of the bottom member of the coil to the base. The current goes through the coil, entering

by one silver wire and passing out by the other. The resistance of the coil is about 150 ohms. A concave mirror is attached to the suspension hook directly above the coil, moving with it.

Sometimes the wires are strained, and sometimes the lower wire

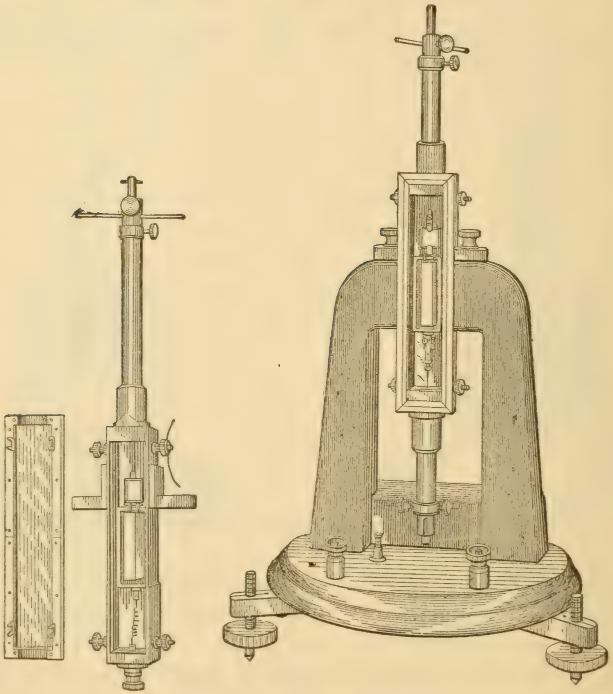


FIG. 469.—DEPREZ-D'ARSONVAL GALVANOMETER.

is left loose. In the latter case, as far as the action of the instrument is concerned, it is only a conductor for the current.

A modern form, as made by Leeds & Northrup of Philadelphia, is shown in Fig. 469. The coil and core are seen best in the left-hand figure, showing the suspension element removed from the magnet and with its glass front taken off.

Ballistic Measurement.—The ballistic galvanometer is used to determine the quantity or coulombs K of electricity which pass through its coils during a very short discharge. If the galvanometer needle moved as the discharge passed, it would receive a weaker and weaker current as the discharge approached its end. In such a case the motion of the needle or other movable element of the galvanometer would not tell anything, as there would be no practicable way of running up or integrating its motions. But the whole discharge may be completed before the needle begins to move. When it does move under such condition, the motion represents the sum of all the actions which have been exerted upon it, whether great or small. The needle under their combined effect will be deflected suddenly, and the limit of its throw will depend upon the sum of these forces.

If the charge passes before the needle begins to move, one ballistic condition will be present.

The motion of the galvanometer indicator may be checked or damped by air resistance or by magnetic induction. Another condition for the ballistic galvanometer to fulfill is that this shall be very small.

Generally, a reflecting galvanometer is employed for ballistic work. Its reflected light spot is received upon a scale four feet or more distant.

Let K indicate the coulombs which produce an instantaneous throw of $k°$ by ballistic action. Let A indicate the amperes of current which would produce the steady deflection $a°$. Let P be the time of vibration of the galvanometer in seconds. When $k°$ and $a°$ are both small, the law of the deflection under ballistic conditions as given above is:

$$\mathrm{K} = \frac{\mathrm{P}}{\pi} \times \mathrm{A} \times \frac{\sin \frac{k°}{2}}{\tan a°}$$

The angle of deflection $a°$ for a given current A amperes must be small. The angle $k°$ must also be small to keep the light spot upon the board. Thus, if the scale board is 4 feet distant from the mirror of the galvanometer, a deflection of 2 feet corresponds to an angle of less than 30°.

If the scale is divided into equal divisions, they may be read

and used instead of angular deflections. Then if we part from degrees and call the two kinds of deflections k and a respectively, we may greatly simplify the formula and let it read thus:

$$K = \frac{P}{\pi} \times \frac{A}{2} \times \frac{k}{a}$$

This will give a result very nearly accurate.

A galvanometer for ballistic work should be of slow periodicity, as P has to be determined, and it is more accurately determined if it is a long period. A heavy moving element, whether needle or coil, lengthens the periodicity and also makes the needle slower in starting, which is a favorable condition.

A usual method of working is to reflect a lighted incandescent lamp filament from the mirror, and to receive its image upon a strip of ground glass, through which the ignited filament shows. Before making a test the galvanometer must be absolutely at rest. This condition is disclosed by the image of the filament appearing motionless on the scale.

It is impossible to measure with accuracy the time of a single swing of the needle or coil of the galvanometer. For this determination the needle is set swinging, and the time of ten or more swings is taken. Dividing the time by the number of swings gives the periodicity P of the instrument.

Ballistic Calculation.—The following example is taken from Ayrton's "Practical Electricity":

With a galvanometer, the needle of which executes eleven complete swings in 6½ seconds, 1 Daniell's cell, having an E. M. F. of 1.07 volts and an internal resistance of 3 ohms, produces a constant deflection of 127 scale divisions when there is a resistance of 10,000 ohms in the circuit, excluding the galvanometer, which has a resistance of 7,500 ohms, and which is shunted with the one one-thousandth shunt. What number of coulombs is discharged through the galvanometer when an instantaneous deflection of 230 = k scale divisions is produced?

The solution is as follows: The periodicity P of the galvanometer is $\frac{6.5}{11}$ or 0.59. The current in amperes A producing the deflection 127, which is a, is found by Ohm's law, $I = \frac{E}{R}$.

The resistance of the battery is 3 ohms, that of the resistance coil is 10,000 ohms. The resistance of the galvanometer and the shunt in parallel with it is $\frac{7560}{1000}$ or 7.560. But as the shunt in parallel with the galvanometer passes 0.999 of the current, one-one-thousandth of the current goes through the galvanometer coils. The total current is therefore $\frac{1.07}{3+10,000+7.56}=\frac{1.07}{10,000}$ approximately. As $\frac{1}{1000}$ of this current acts upon the galvanometer, because of the shunt the current A is $\frac{1.07}{10,000,000}$ ampere.

Returning to our formula and substituting these values, we have:

$$K=\frac{0.59}{\pi}\times\frac{1.07}{2\times 10,000,000}\times\frac{230}{127}$$

which gives as answer 0.01822 micro-coulomb.

The answer, it will be observed, is given in micro-coulombs. This is done to avoid the six more decimal places which would be required were the answer given in coulombs. The above might have been put thus:

$$\text{Micro-coulombs}=\frac{0.59}{\pi}\times\frac{1.07}{2\times 10}\times\frac{230}{127}$$

The Tangent Galvanometer is an instrument whose deflections can be interpreted to give directly the intensity of the current which passes through them. Its construction is based on the following principle: If a magnetic needle is placed in a uniform field of force due to a current, which field is at a right angle to the terrestrial field, it will be deflected at an angle greater or less as the strength of the field is greater or less. The law of the deflection will be that the tangent of the angle of deflection will be proportional to the strength of the current producing the field.

The construction of the tangent galvanometer is shown in the cut, Fig. 470. A ring of large diameter stands vertically on a support. The current whose intensity is to be determined passes directly through an insulated conductor wound around the ring. For heavy currents a single turn of wire would be sufficient. A

magnetized needle is supported at the center of the ring. The needle must be as short as possible. For a ring 12 inches in diameter, a needle 1 inch long may be used. As the needle will be too short to admit of a scale being used large enough to give good readings, a very light index is attached to it, which index is several inches long. A dial of corresponding diameter is under the index.

The dial can be graduated in degrees. Then a reference to a table of natural tangents will give the relative value of the current intensity producing any given deflection. The dial can also be graduated so as to give tangent readings. Thus, the tangent of 5° is 0.08749, that of 10° is 0.1804, that of 15° is 0.268, and so on. A direct-reading tangent scale might have the reading 8.75 correspond to its 5° point, with the intermediate ones filled in. The numbers put upon the scale would be integral ones, starting from 1 and extending on either side of the zero point.

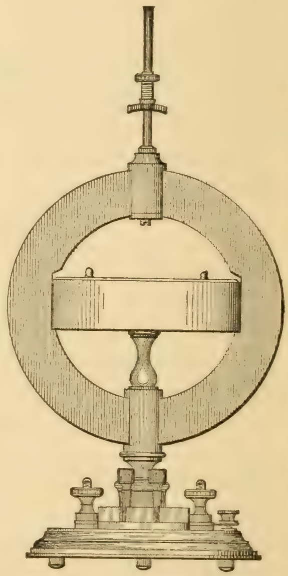


FIG. 470.—TANGENT GALVANOMETER.

The angle of 45°, whose tangent is equal to unity, would on the above basis be marked 100. The point of maximum sensitiveness is at 45°.

The tangent galvanometer must be placed in the plane of the earth's magnetic meridian when it is to be used on the tangent principle.

This instrument is sometimes called the tangent compass.

The Sine Galvanometer is a galvanometer whose indications of strength of current passing vary with the sine of the angle read off its scale. It has a vertical coil with a magnetic needle in the center pivoted so as to rotate in a horizontal plane. Thus far it resembles the tangent compass. In use the coil is turned into the plane of the magnetic meridian, as shown by the magnetic needle. The current is then turned on and the needle is deflected.

The coil is turned in the direction of the deflection, following the motion of the needle, which still moves a little as the coil approaches its plane of position. Eventually the coil is brought accurately into line with the needle, and the angular deflection from the original position or zero point is taken. The strength of the current is proportional to the sine of this angle.

The proportions of length of needle to diameter of coil are without effect on the exactness of the sine law. The coil can be made of small relative diameter compared to that necessary in a tangent compass. This increases the sensitiveness. The sensitiveness also increases with the angle of deflection.

This instrument is also called the sine compass.

The Thomson or Kelvin Absolute Electrometer is based upon

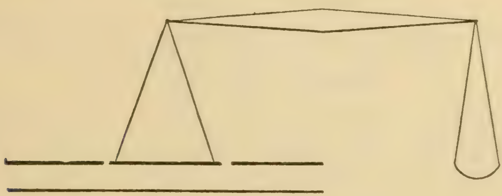


FIG. 471.—SIR WILLIAM THOMSON'S ABSOLUTE ELECTROMETER.

the attraction exercised between two electrified surfaces. An insulated metallic disk is hung from one end of a balance beam. It hangs horizontally in an opening in a larger annular metallic plate called the guard ring, which is also insulated. Sometimes it is suspended by a spring. When uncharged it hangs a little above the plane of the guard ring. Below the annular plate, a little distance from it and parallel with it, is another insulated metallic plate in electrical contact with the movable plate. The cut, Fig. 471, shows the disposition of parts.

The principle is that two surfaces oppositely electrified attract each other with a force proportional to the square of the electromotive force between them. When an instrument of this description is calibrated for direct current, it can be used for alternating currents, and will indicate their effective values.

To use it, the terminals whose potential difference is to be de-

termined are connected, one to the lower plate and the other to the suspended plate. The force with which they attract each other is determined by weighing it, if a balance, or by deflection of the spring, if the spring construction is employed. The movable plate must be brought to accurately lie in the plane of the guard ring. The distance between the upper and lower plates must be accurately known. The guard ring and circular plate must be of identical potential, and this is why they are in electrical connection through the suspension rods or spring carrying the movable plate.

Let E = electromotive force between the upper and lower plates.

d = the distance between the same.

F = the attraction between the plates in dynes.

$$(1 \text{ dyne} = 1 \frac{1}{981} \text{ gramme})$$

a = the area of the movable plate in square centimeters.

$$\text{Then } E^2 = \frac{720{,}000\, d^2\, F}{a}$$

Another method of using it is to keep the upper plate at a constant potential by some source of constant electromotive force, which may be a small influence machine, somewhat on the Wimshurst type. The lower plate is alternately connected to the earth and to the terminal whose potential is to be measured. Each time the connection is made, the attraction of the disk for the lower plate is determined. The difference between the potentials of earth and terminal gives the potential of the body referred to the earth.

Galvanometer Shunts.—A galvanometer may be too sensitive for some specific test. The voltage may be sufficient to produce a current which would throw the light spot off the scale, or which would deflect it so nearly to 90° as to make its readings worthless. A right angle or 90° is the limit of motion of a galvanometer needle, and in the neighborhood of 90° its readings are very inexact. Thus a galvanometer too sensitive for the work it has to do would have its needle deflected so nearly over 90° that it would lose accuracy. If the current is split up, and only a portion is passed through the coils of the instrument, it can be reduced in sensitiveness so as to bring the readings within a good working portion of the scale. To split up the current,

a known resistance is connected across the galvanometer terminals, so as to be in parallel with the coils. These resistances are definite fractions of the resistance of the galvanometer coil. They are termed galvanometer shunts.

A galvanometer shunt, such as supplied by instrument makers, is shown in Fig. 472, and the diagram, Fig. 473, shows the connection and its relation to the galvanometer. It will be seen that it is in parallel with the instrument, and passes a fraction of the total current, whose value depends on the relative resistance of the galvanometer and of the shunt, as explained below.

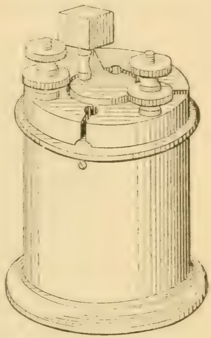


FIG. 472.—GALVANOMETER SHUNT.

To reduce the sensibility of the galvanometer to $1/n$ of its normal value, the resistance must be equal to that of the galvanometer g divided by $n - 1$. Suppose that a shunt box is used which can reduce the sensibility to 1/10, 1/100, and 1/1000 of the normal value. Then the resistances of the three shunts are $g/9$, $g/99$, $g/999$, calling g the resistance of the galvanometer.

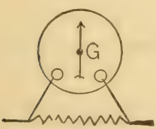


FIG. 473.—SHUNTED GALVANOMETER.

When a shunt is put in parallel with a galvanometer, the proportion of the total current which passes through the galvanometer is equal to the quotient obtained by dividing the resistance of the shunt by the combined resistance of the two pieces, galvanometer and shunt. This quotient multiplied by the total current gives the galvanometer current.

The resistance of the galvanometer and shunt is equal to the product of the resistances divided by their sum.

Compensating Resistance.—When a galvanometer is shunted, the decrease in resistance causes an increase of current. A resistance in series, called compensating resistance, is used to bring the current back to its former strength. The compensating re-

sistance is equal to the square of the galvanometer resistance divided by the sum of its resistance and the resistance of the shunt.

Constant of a Galvanometer.—The French constant is the deflection produced in a galvanometer by a Daniell's cell in a circuit of total resistance of one meg-ohm or one million ohms. The resistance of the battery and galvanometer are included. In England the constant of a galvanometer is the number by which its indications must be multiplied to reduce them to a given unit of current.

Another form of galvanometer constant applicable to tangent galvanometers is used in England.

Let $n =$ number of turns of wire in the coil.

$r =$ radius of coil.

Then

$$\text{constant} = \frac{r}{2\,\pi\,n}$$

It appears in the following formula: Let

H = horizontal component of earth's magnetism in dynes.

I = current intensity in C. G. S. units.

S = angle of deflection of needle.

n and r = values given above for them.

Then:

$$\mathrm{I} = \frac{r}{2\,\pi\,n} \times \mathrm{H} \tan \mathrm{S}.$$

And this value multiplied by 10 will give the current in amperes.

A still more general definition of the working constant as used in every-day practical work in this country is the following:

The working constant of a galvanometer is the number of scale divisions of deflection that would be obtained by causing the current from the given battery to pass through the galvanometer and a resistance of one meg-ohm.

Determination of the Constant.—Galvanometer constants as used in France, England, and America vary because it is an arbitrary working figure only. Its determination for practical use is now to be described.

In the diagram, Fig. 474, G represents a galvanometer, B a battery, S the galvanometer shunt, and R a known resistance. Sup-

pose the shunt to be $g/999$. This reduces the sensibility of the galvanometer to 1/1000 of its normal sensibility. Suppose the resistance R to be 100,000 ohms. When the circuit is closed, the galvanometer will be deflected. Without the shunt the deflection would be theoretically 1000 times as great, on the assumption that the deflections vary as the current. This assumption only holds true for very small deflections in reality, and is applicable in this case because in the actual test deflections within this limit are used.

The shunt makes the deflection 1/1000 as great as if there were no shunt there; the resistance makes it 10 times as great as if a meg-ohm (1,000,000 ohms) were the resistance instead of 100,000 ohms. Therefore, for a meg-ohm resistance and without any shunt the resistance would be equal to that shown multiplied by 1000 and divided by 10.

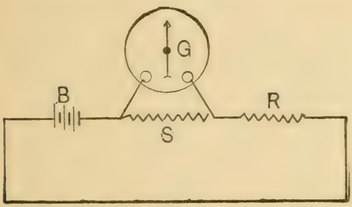


FIG. 474.—DETERMINATION OF THE GALVANOMETER CONSTANT.

The general rule for determining the working constant with the connections shown in Fig. 474 is as follows:

The working constant is equal to the product of the deflection of the galvanometer multiplied by the multiplying power of the shunt, and by the meg-ohms resistance in series with it.

In the case cited the multiplying power of the $g/999$ shunt is 1000, the meg-ohm resistance in series is 1/10 meg-ohm. The deflection is multiplied by $1000 \times 1/10$.

Suppose a deflection of 250 scale divisions was given with the resistance and shunt as above. The constant would be:

$$250 \times 1000 \times 1/10 = 25{,}000.$$

Such would be the constant for a D'Arsonval galvanometer with 40 or 50 volts battery. As high a constant as 2,000,000 can be obtained for laboratory practice.

A battery giving 50 volts is enough for ordinary work. By increasing this voltage the deflection is increased, and consequently the galvanometer constant is also increased. In delicate work a potential of 600 volts is sometimes used. In ordinary work 100 volts is not excessive.

Figure of Merit.—This is the resistance of a coil placed in series with a galvanometer, so that a potential difference of one volt will produce a deflection of one division on the scale.

Sometimes a Daniell cell (E = 1.07 volt) is taken as giving the potential for the figure of merit. Properly, the entire resistance of the circuit should give the figure of merit, not merely that of a resistance coil in series with the line. But in practice the resistance of the galvanometer coil so far exceeds that of the rest of the circuit that it can sometimes be used directly without adding in the rest of the resistances.

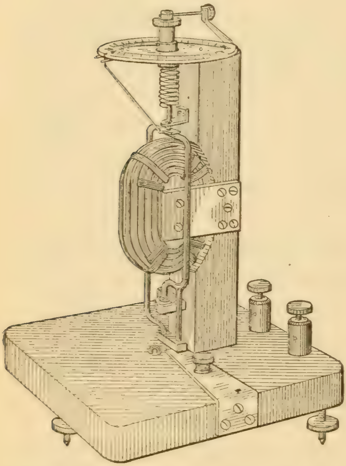


FIG. 475.—SIEMENS'S DYNAMOMETER.

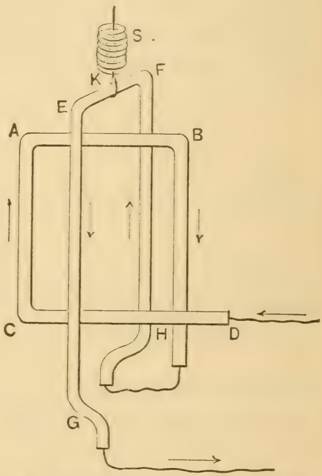


FIG. 476.—CONNECTIONS OF SIEMENS'S DYNAMOMETER.

Galvanometer Resistance.—For thermo-electric work a galvanometer of about ¼ ohm resistance is used. Thomson's galvanometers have from 5,000 to 10,000 ohms resistance, with between 2 and 3 miles of wire 0.004 to 0.008 inch diameter. Some galvanometers wound with German-silver wire have 50,000 ohms resistance, and a single Daniell's cell through 20 meg-ohms resistance will move the index through 200 divisions of the scale.

Siemens's Dynamometer.—This instrument, whose construction

is as simple as its theory, is the standard instrument for measuring alternating currents. It is shown in the cut, Fig. 475. A fixed coil of a number of turns of wire, 55 in one pattern, is mounted immovably as shown. The axis of its central opening is horizontal. A movable coil surrounds the central immovable one. The latter has comparatively few turns—often it has only one. The relation of the two coils is shown in Fig. 476, in which A, B, C, D represents the immovable coil, and E, F, G, H the movable one. The current enters at D or G, and passing through both coils in series, as shown, establishes fields, which tend to pull the coils into parallelism. The movable coil has its two lower terminals one above the other in line with the spring suspension S at K, and the three points are exactly in the axis of the coil, so that it is free to rotate under the smallest force. On this freedom depends its sensitiveness.

Near the base of the machine is a mercury cup, and immediately below it is a second one. The ends of the movable coil dip into these cups, which are vertically over each other. The current, entering by a binding post, goes through the immovable coil and then to one of the mercury cups. Passing through the movable coil, it enters the other mercury cup, which is connected to the other binding post, by which the current leaves the instrument. Thus the coils are connected in series with each other, and the entire current to be measured goes through each.

The movable coil is kept in a vertical position by a spiral spring. The axis of this spring is vertical, it is fastened to a bracket directly over the mercury cups, and its lower end by a wire is connected to the center of the upper bend of the movable coil. Above the spring is a horizontal dial. A handle to which the spring is attached rises from the center of the dial, and an index is attached to it. By turning the handle the index can be moved over the face of the dial like a hand of a clock. The dial is graduated around its edge.

A second index rises from the movable coil, passes by the edge of the dial, and is bent over across the graduated scale on the dial. Its position can thus be determined by the zero point on the scale. A plumb bob or level is used to set the instrument level, and sometimes connections are supplied, so that different numbers

of turns of wire of the fixed coil can be thrown into the circuit.

Normally, when the index on the handle is set at zero, the index of the coil will also be there, the points of the indices facing each other and coinciding in angular position. This is when no current is passing. The coils will then be at right angles to each other, and the spring will be without any torque or turning force (moment). If a current is passed, the movable coil will tend to turn and place itself parallel to the other one. By turning the handle this tendency is resisted, and the coil index is brought back to zero. This strains the spring, which now exercises torque equal to that of the coil. The angle through which the index of the spring is turned is proportional accurately to the square of the current, whether it is an alternating or direct current. This is because of the law that the action between two coils such as those of the dynamometer is equal to the product of the currents passing through them. But as these coils are in series, the product of the currents is the square of the current.

This instrument is as far as the coils are concerned a zero instrument. Its indications depend on the values of the squares of the deflections of the spring index. Hence if it is calibrated by passing a single current of known value through it, it is calibrated for all currents within its range of action.

The advantages of the instrument are several. The parts acting on each other occupy exactly the same relative positions when the reading is taken. Another is that it contains no permanent magnet. The field established by such is liable to change, although as magnets are now made by makers of reputation, there is little danger of any such change. Its simplicity and approach in action to being an absolute instrument are also advantages.

Sometimes two stationary coils are used of different number of turns, and one or the other is used according to the current to be measured.

The instrument should be set up so that the 0° diameter of the scale coincides with the magnetic meridian of the earth. This prevents it from being acted on by the earth's magnetism.

Rheostats.—An early form of resistance for use in experimental work is the rheostat. It is still in extensive use in labor-

atories. It consists in its most usual type of construction of a bare wire, often of iron or German silver, which is wound around a cylinder. If the cylinder is of metal—and it is often a piece of wrought iron pipe—it must be insulated from the wire. Asbestos paper is a good material for this purpose. The wire is wound around it, with the turns as close to each other as possible without touching each other. One end of the wire is connected to the circuit. The other terminal of the circuit is connected to a sliding contact, which latter is mounted on a bar, so as to slide longitudinally up and down the cylinder making con-

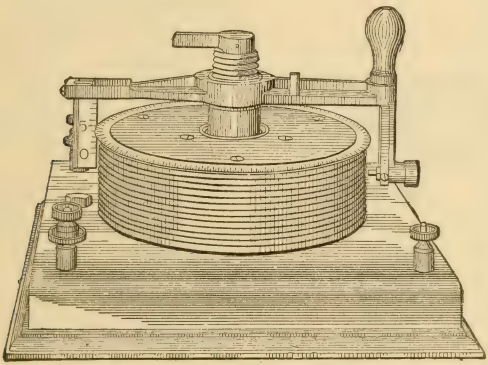


FIG. 477.—LABORATORY RHEOSTAT.

tact with the wire. The farther it is placed from the end connected to the circuit terminal, the more of the wire will be thrown into the circuit; and the greater this length of wire is, the greater the resistance is also. As described, the wire is brought into the circuit one turn at a time. By mounting the cylinder so as to rotate, the wire can be brought into circuit a fraction of an inch at a time.

Many varieties of the rheostat have been constructed.

The cut, Fig. 477, shows a very delicate rheostat for use with a potentiometer or similar apparatus. A helical line on the surface of the cylinder shows where a wire is secured. The small screw projecting from the center of the apparatus carries an arm,

which has a contact point which can be brought in contact with any part of the wire. As shown in the cut, a scale is seen on the left. This reads one division for each turn of the handle. The screw rising from the center is of the same pitch as that followed by the wire on the drum. A circular scale on the upper edge gives the fractions of a turn. The position of the handle determines the point of contact with the wire. The position of this point brings an amount of the wire indicated by the reading of the two scales into the circuit. The resistance of all the wire being known, the resistance of the fraction is calculated.

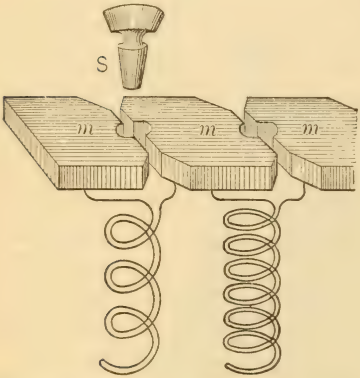


FIG. 478.—ARRANGEMENT OF RESISTANCE COILS.

Resistance Coils.—A resistance coil is made of a length of insulated wire of known resistance. As the wire may be of very great length, it is coiled compactly. To avoid inductance it is doubled before coiling. The current goes through one half of the coil in one direction and through the other half in the other, and the two inductances counteract each other almost perfectly. Insulated German-silver wire is a usual material for the coils, as its coefficient of change of resistance by temperature variations is very low. Other alloys are used by different makers.

Resistance Boxes.—A quantity of such coils are mounted in a single box called a resistance box. The resistance box should have the following qualities: Accuracy of adjustment, dependent on the individual coils being correct, and small sensibility to changes of temperature, dependent on the alloy of which the wires are made. The wire should be double silk-coated. The doubling of the wire and its connection to contact blocks on the top of the box is shown in Fig. 478.

The wire is wound on spools or reels. Some makers use thin

brass reels to facilitate cooling; others use ebonite or paraffined wood for the reels. The wire is liable to be heated by the passage of a current, and it is this heating which the brass reels are intended to dispose of. Wire is wound on each coil until the desired resistance is attained, the last corrections are applied, and it is then steeped in melted paraffin wax. The resistance of a wire is changed by bending. It is therefore necessary to test the resistance of the coil after it is wound. The object of the paraffin wax is to exclude moisture.

Resistance Wire.—A typical composition of German silver is the following: Copper, 50 parts; zinc, 30 parts; nickel, 20 parts. All parts are parts by weight.

The resistance of the wire is increased by increasing the percentage of nickel. The wire should be well annealed to make it as soft as possible.

The British Association Standard Ohm.—The alloy adopted for this standard was either German silver or an alloy of two-thirds silver and one-third platinum by weight.

Arrangement of Coils.—On the top of a resistance box are seen a number of blocks of brass. To each block two terminals are connected by tapping into sleeves or into the undersurface of the block, and by soldering. One is a terminal of one coil, and the other that of its neighbor. Grooves are made in the vertical sides of the blocks facing each other. These are accurately reamed out to fit the slope of brass plugs with insulating handles. Referring to Fig. 478, it will be seen that if a plug is inserted, the coil beneath it will be short-circuited or cut out. Numbers marked on the top of the box indicate the resistance of each coil below the number. The resistance of a box with the plugs out is equal to the sum of the resistances marked on its top. Frequently there is a pair of blocks, which if unplugged cut out the whole set of coils. This is often called the infinity hole or plug.

The cut, Fig. 479, shows the top of a modern resistance box. The Wheatstone bridge box is merely a special form of resistance box with the coils arranged for convenient bridge operations.

The order of resistances of the coils varies according to the ideas of the makers.

Siemens's Plan is one of the oldest arrangements of resistance

coils in a resistance box. A series of coils are arranged between blocks. The successive values of the coils are 1, 2, 4, 8, 16, 32, etc., as far as desired. By plugging between all the coils, the resistances are all short-circuited. By removing any single plug the resistance named above it is thrown into circuit. Starting at the left, taking out the first plug throws in 1 ohm; taking out the second throws in 2 ohms, giving a total of 3; taking out the third also throws in a total of 7, and so on. By taking out any number of plugs, whether consecutively or not, the sum of the resistances marked will be thrown into the series. The

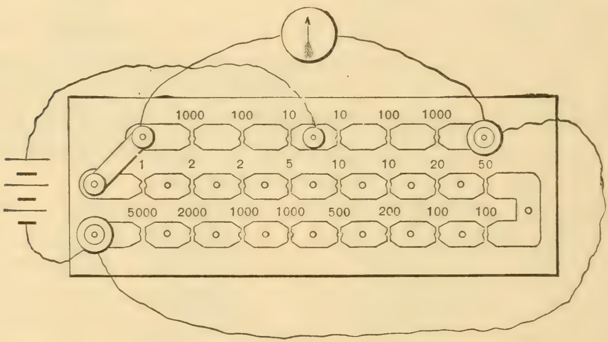


FIG. 479.—TOP OF A WHEATSTONE BRIDGE RESISTANCE BOX.

combination is very interesting, but it is obsolete, as it does not lend itself to easy decimal summation.

Modern Arrangements.—The following are approved systems of resistances for 16-coil boxes. It will be seen that any number of ohms down to units can be obtained by different combinations:

(*a*) 1, 2, 2, 5, 10, 10, 20, 50, 100, 100, 200, 500, 1000, 1000, 2000, 5000.

(*b*) 1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1000, 2000, 3000, 4000.

(*c*) 1, 1, 3, 5, 10, 10, 30, 50, 100, 100, 300, 500, 1000, 1000, 3000, 5000.

The easiest way to plug in a resistance is to start with all the plugs in place. A glance at the figure indicating the ohms desired

will show what plugs to remove to make the sum of resistances thrown in equal thereto.

A disadvantage is to be found in this type of arrangement. A plug is needed for every coil, and when a number of coils are cut out, a quantity of plugs equal to their number must be used. A single badly-placed plug will introduce unknown resistance. The trouble is emphasized by the fact that this last is most apt to occur when the greatest number of plugs are in place. This is when the resistance is lowest and when any additional resistance will be the largest per cent of the total.

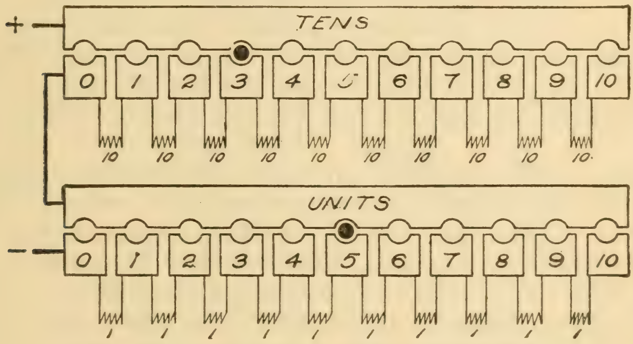


FIG. 480.—DECADE PLAN OF RESISTANCE BOX.

The Decade Plan is an improvement that has been recently introduced. The diagram, Fig. 480, shows one of the arrangements.

The lower set of coils are of one ohm resistance each and connected in series. Each block has a plug groove in its side facing outward. A long bar of brass is mounted opposite the row of plugs, with grooves in it corresponding to those in the blocks. The next row of coils are of 10 ohms resistance each, and are arranged in series with blocks. A long brass strip is provided for them also. The connections for the circuit are marked + and — in the diagram.

In the above arrangement a single plug inserted in a hole between block and bar will give any value in a decade. Thus the

two plugs indicated by the black spots give 35 ohms resistance. No more plugs than these two are ever needed for this box. There is less danger of losing plugs, of loose contacts, and of straining the junction of the brass blocks and the hard-rubber box top. The latter trouble sometimes leads to warping the rubber, as the plugs are forced down between the blocks. The decade plan lends itself to the use of sliding contacts, either on a straight line or arranged dial fashion. This substitute for plugs is coming into use.

The number of coils used on this system is rather large. The Leeds & Northrup Company have other combinations, of which the following, Fig. 481, is an example. A 1-ohm, 3-ohm, 3-ohm, and 2-ohm coil are arranged in series as shown. The terminals are indicated by + and —. If 1 and 5 are connected, the resistance will be zero. If 2 and 5 are connected, only 1 ohm will be left in circuit. If 4 and 1 are connected, 2 ohms will be left in circuit. By following this out, it will be found that every resistance from 1 ohm to 9 ohms can be given by these four coils.

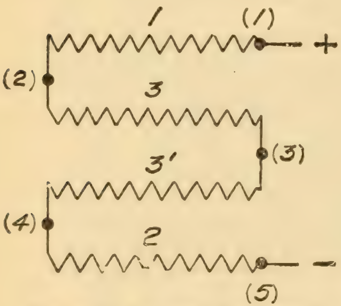


FIG. 481.—DECADE PLAN FOR RESISTANCE BOX.

By the block and plate arrangement a single plug does all the connecting for the nine values of the four coils.

The above arrangement takes care of each decade with only four coils and one plug to the decade.

Details in the Construction of Resistance Boxes.—The hard-rubber surface must be clean to avoid a diminution of resistance; therefore all parts of the rubber must be accessible for cleaning. A defect in some constructions of resistance boxes is that the surface of the rubber between the pairs of blocks cannot be conveniently got at for the removal of dust. The plugs should go down below the shoulder or top of their tapering ends to avoid the formation of ridges by wearing and friction against the edges of the contact blocks.

Shellac for coil insulation is now preferred by the best makers to paraffin. It is put on in solution, dried and baked. Wire with a low-temperature coefficient must be used for the coils. The baking of the shellacked coils tends to equalize the winding strains and to artificially age the wire. Metal spools by their better cooling powers have the effect of reducing temperature errors and changes.

Metal Spools are made by Leeds & Northrup in two parts, being divided longitudinally. The halves are insulated from each other, and secured together by rings of insulating material at top and bottom. The spool is covered with silk, shellacked, and wound with the wire. Each half of the tube is connected to its own contact block or plate, and the ends of the wire are soldered each to one-half of the spool. Thus there are no long ends of wire to be disposed of, and connecting the spool to its holding bolts or studs connects at the same operation the ends of the coil.

Practical Notes.—The plugs must be perfectly clean. In constructing the box, the taper of the plugs must match that of the holes. Filing and rubbing with fine emery paper is sometimes recommended, but such treatment should be sparingly used, as it will tend to spoil the shape of the plugs. Burnishing with the back of a knife is good. In inserting the plugs a slight twist should be given. Never touch the metal part of a plug with the fingers. In putting in or taking out a plug, be careful not to disturb the ones next to it. A plug from one box should not be used in another unless it has the same taper. A well-arranged bridge box will answer for the measurement of resistances from 1/100 ohm up to 1,000,000 ohms. A larger size with 10,000-ohm coils may extend over a range of 1/1000 ohm to 10 meg-ohms (10,000,000 ohms). Thicknesses of the wire for the different coils are given thus:

Coils of 1 ohm....................No. 18 to 21 B.W.G.
Coils of 10 ohms....................No. 20 to 29 B.W.G.
Coils of 100 ohms....................No. 25 to 34 B.W.G.
Coils of 1000 ohms....................No. 32 to 40 B.W.G.

A high-class resistance box or Wheatstone bridge box can have its top lifted off and turned upside down for inspection of the

coils, which are attached to the top and are lifted with it. A damaged coil can be removed and another put in its place, thus avoiding the necessity of sending the entire box to the makers.

Wheatstone Bridge or Bridge Box.—This is a resistance box with its coils so arranged that the connections of the Wheatstone bridge may be carried out with it. It has four binding posts for the end and galvanometer connections. It has already been shown in Fig. 479.

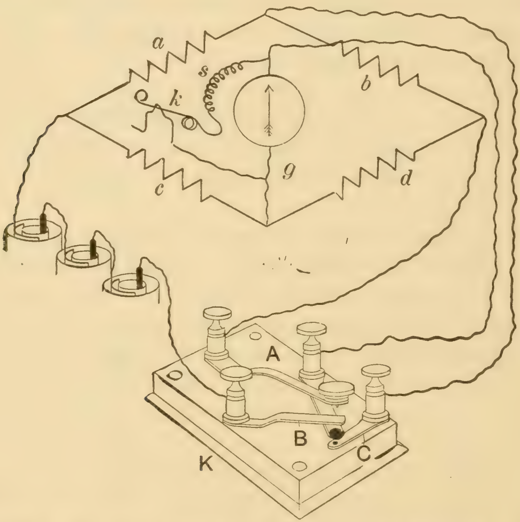


FIG. 482.—DIAGRAM OF WHEATSTONE BRIDGE.

The Wheatstone Bridge is an apparatus for determining the resistance of a conductor.

If a conductor carrying a current is divided into two parallel conductors for a portion of its length, the following law will always exist: For every point on one of the parallel conductors there will always be a corresponding one on the other, between which, if they are electrically connected, no current will pass.

Let the Wheatstone bridge be represented by a diamond, Fig. 482, with opposite points connected. Let the four arms of the

bridge be designated by a, b, c, and d. If no current flows through the wire indicated by g, the proportions will hold:

$$a : b :: c : d \text{ and } a : c :: b : d.$$

In a proportion if three of the quantities are known, the fourth one can always be found by the arithmetical "rule of three." If therefore any three of the resistances are known, and if no current passes through g, the fourth or unknown resistance can be calculated by the rule of three.

Suppose that an unknown resistance is to be determined. It

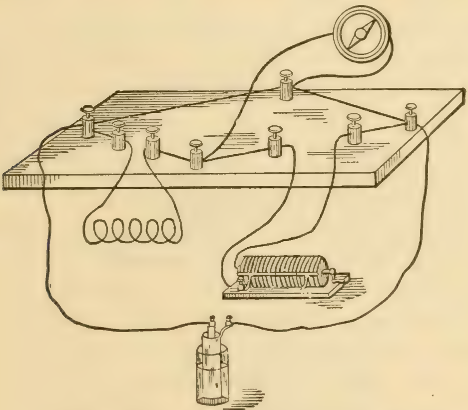


FIG. 483.—SIMPLE WHEATSTONE BRIDGE.

is placed in the bridge connection, at d it may be; theoretically, the place is indifferent. The current goes through it, and it must constitute the entire resistance of the arm d. Known resistances are put in for a and b. Suppose they are $a = 100$ ohms and $b = 5$ ohms. Then one resistance after another is tried at c until no current passes through g. Suppose that this was 57 ohms. We then have the proportions:

$$100 : 5 :: 57 : x \text{ or } 100 : 57 :: 5 : x$$

from either of which we find that

$$x = 2.85 \text{ ohms.}$$

This is the law of the Wheatstone bridge The apparatus is one of the most used in electrical work. To ascertain when no cur-

rent passes through *g*, a sensitive galvanoscope may be used. It need not be a galvanometer, that is to say, it need not be a measurer of current; it is enough if it shows the presence of a current. It must be sensitive, as the slightest current must be shown by it if it exists.

Fig. 483 gives a perspective view of a simple bridge to demonstrate the principle.

Operation of the Wheatstone Bridge.—It may be operated on two principles. One of the resistances only may be changed until no current passes through the galvanometer connection, or two of the connections may be changed simultaneously, one being increased as the other is diminished. The latter method is used in a form called the meter bridge originally, but since its first use modified in various ways, so that it is no longer a meter bridge. The name meter indicated that two of the limbs, *a* and *b* for instance, are one meter in length when taken together, being represented by a single straight wire.

Another thing to be noted is that it is only necessary to know the value of one of the three resistances. If the proportional value of the other two to each other is known, it is sufficient.

What is known as a Wheatstone bridge is usually a box filled with resistance coils and with connection points or binding posts representing the points of the diamond. If the cut, Fig. 479 representing the horizontal plan of a bridge, be examined, it will be seen that the points of connection of the wires from the battery represent the ends of the diamond. The galvanoscope is connected to points representing the top and bottom of the diamond. The loose wire running from the right-hand binding post, where the galvanometer is connected to the battery connection, is the wire whose resistance is to be measured. By putting in and taking out plugs, the relations of the resistances can be varied until the galvanoscope reads zero.

Null Method.—One great advantage about the bridge method is that the galvanoscope reads zero always when the resistance is determined. A calibrated instrument is not needed. It is what is called a null method.

The Meter Bridge has been used for the most delicate researches. The cut, Fig. 484, shows the connections. The character-

istic part from which it takes its name is the wire in this instrument stretched three times along its front. This wire represents two of the arms of the bridge. A sliding piece K moves along it, and by depressing a key connects the conductor from the galvanometer to the wire. This point represents the top or bottom of the diamond. The position of the point read off on the scale gives the ratio of resistance of the two sides represented by the stretched wire. By using one or the other of the three leads of the stretched wire, or by using two or three of them

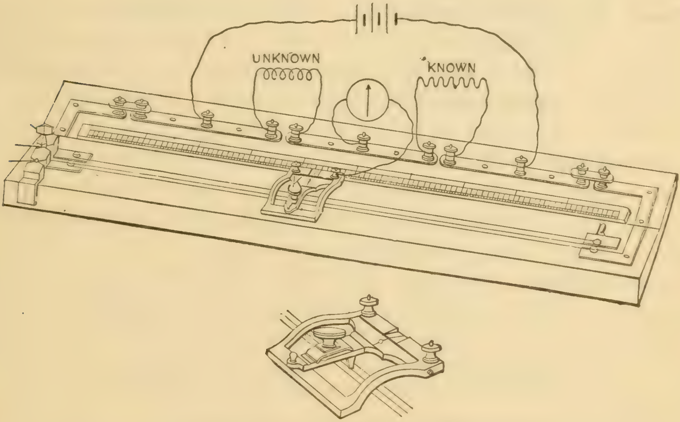


FIG. 484.—METER BRIDGE.

simultaneously, all sorts of proportions between the parts to right and left of R can be brought about. The known and unknown resistance represent the other legs of the diamond, and the point where the other conductor from the galvanoscope is connected is the end of the diamond. The small figure shows the contact piece which is moved along the wire.

Bridge Key.—In using the bridge, the current is only turned on momentarily for each trial adjustment, until the zero reading is reached. This would set the galvanoscope swinging, owing to the capacity of the elements of the bridge or of the conductor or to the capacity or inductance of the unknown resistance. A

key is used which makes two contacts in succession. The first connects the battery with the bridge circuits, and the second brings the galvanoscope into its circuit. Thus in the cut, Fig. 482, when A is depressed, it first makes contact with B, thus bringing the battery and the four arms of the bridge on closed circuit. This instantly charges all parts and expends any inductance. A further depression of the key brings A, B, and C in contact, which operates to throw the galvanoscope into its proper circuit across the diamond. Two separate keys may be connected, so as to effect the same result.

Shunt to the Galvanoscope.—This is sometimes used to diminish its sensibility for the first trials. As the work approaches its finish, the shunt key is opened, allowing the galvanoscope to operate with its full degree of sensitiveness. In the cut, Fig. 482, the shunt is indicated by *s* and the shunt key by *k*.

Proportional Coils.—This term is applied to the arms of the bridge opposite to the unknown resistance and the arm in series with it. Thus in Fig. 482 if *c* or *d* represents the unknown resistance, *a* and *b* are the proportional coils.

Galvanoscope.—Although this term has been used, the galvanoscope actually employed is a galvanometer in most cases, and a highly sensitive reflecting instrument is adopted for delicate work. As a galvanoscope the telephone receiver is sometimes employed.

Conditions of Sensitiveness.—The galvanometer must be sensitive. On inspecting the diagram, Fig. 482, on page 632, it will be seen that the battery and galvanometer can be interchanged. The one which has highest resistance should be placed so as to connect the junction of the two arms of highest resistance with the junction of the two arms of least resistance. Thus, if the resistances are $a = 1$ ohm, $b = 100$ ohms, $c = 4$ ohms, and $d = 400$ ohms, the higher resistance apparatus or appliance, whether it is battery or galvanometer, should connect the junction of *a* and *c* with that of *b* and *d*. The galvanometer will almost always have the higher resistance. With galvanometers equal in all other respects except in the thickness and length of wire winding, the resistance for greatest sensitiveness will be expressed by the following expression, referring to Fig. 482:

$$\frac{(a + b)\ (c + d)}{a + b + c + d}$$

This is not a practical consideration, as the galvanometer cannot be changed for every new testing.

Direction of Deflection.—The galvanometer will deflect one way for one change of relative resistances and the reverse way for the other change. This will hold only for the identical battery connections. It is recommended by some to mark upon the work table some indication for these deflections. Then by noting whether it is to left or right, the operator will know whether to increase or diminish the given resistance. Ordinarily, it will be

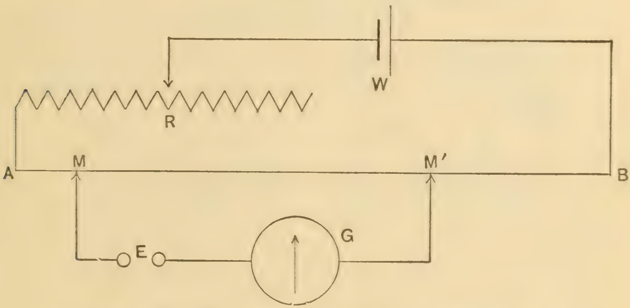


FIG. 485.—PRINCIPLE OF THE POTENTIOMETER.

one resistance that will be varied. The others will be plugged in and left untouched, perhaps for a number of tests.

The Potentiometer is an apparatus for measurement of resistances, current strengths, and potential differences. It has acquired in late years most extensive application. Modern electric measurement practice tends or should tend in the direction of null methods. The potentiometer uses one of these. A reflecting galvanometer may be and generally is used with the potentiometer. Its function is simply as a galvanoscope, just as in the Wheatstone bridge method. When it shows no potential difference, the reading of the resistance coils gives the result of the experiment.

Principle of the Potentiometer.—In Fig. 485 W is a battery

giving a constant current, R is an adjustable resistance, A B is a resistance divided into 150,000 parts, and by movable contacts M M′ different lengths of it may be thrown into parallel with the circuit containing the galvanometer G and at E a battery not shown in place, because various cells are used there, E indicating the binding posts for connecting them. For general requirements the drop between M and M′ must be at least 1.5 volts under the action of the main battery W, which is not a standard one.

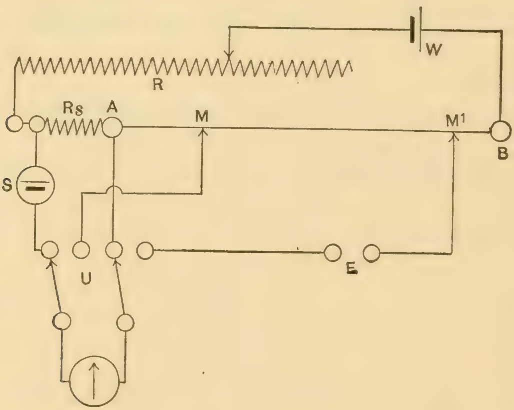


FIG. 486.—POTENTIOMETER CONNECTIONS.

The standard cell is introduced at E, and the points E and E′ are so set that the number of divisions of A B included between them represents the voltage of the standard cell. Suppose this voltage to be 1.434, then M and M′ should include 1,434,000 divisions of A B between them. The resistance at R is now varied until the galvanometer G shows a zero reading. For the standard cell there is substituted a cell whose electromotive force is to be determined. The distance between M and M′ is adjusted until the galvanometer again reads zero. The direct reading of the divisions gives the voltage of the cell.

This merely gives the principle. In Fig. 486 is shown one of the developments. The galvanometer is seen at the bottom of

the diagram. A double-throw switch throws it into circuit with the standard battery S or the battery to be tested, connected at E. The drop against which the standard cell S is balanced is the fixed resistance R *s*. By varying the resistance R, the zero reading of the galvanometer is secured with the connections shown in the diagram. The double-pole switch is then thrown to the right and M M′ adjusted until a zero reading is obtained. The divisions of A B included between M and M′ give directly the voltage of the cell at E. R *s* is chosen of such resistance as to secure this relation.

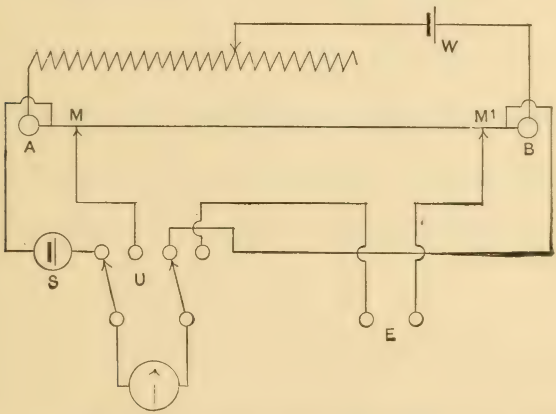


FIG. 487.—POTENTIOMETER CONNECTIONS.

Another development is shown in Fig. 487, which approaches more closely than the last to the conditions of Fig. 485. The standard cell connects at fixed points on A B distant a number of divisions expressing as before its voltage. The cell to be tested is connected by a right-hand movement of the switch, and its voltage is determined as before for M M′.

High-Voltage Determinations with the Potentiometer.—If the voltage to be determined exceeds that of the standard cell considerably, resistance is put in series with the cell to be tested. Connections to E are taken from known divisions of the resistance. Thus, suppose a 30-volt battery were to be measured, which is

twenty times the capacity of the instrument. The battery would be connected through a resistance which might be 1,000 ohms. Taps from portions of the 1000-ohm resistance, including 50 ohms between them, would be connected to E. The reading between M and M′ multiplied by 20 would give the voltage of the battery.

In Fig. 487*a* the source of electromotive force which is to be measured is connected at E. M. F. By means of the switch N different portions of the resistance Q Q′ can be connected to the potentiometer at P. For a high electromotive force the fraction E Q′ of the resistance could be connected, giving a fraction of

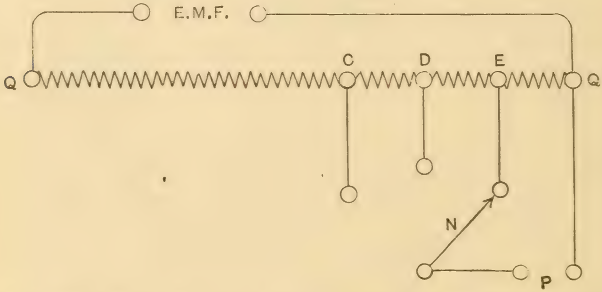


FIG. 487*a*.—HIGH-VOLTAGE CONNECTIONS FOR POTENTIOMETER.

the electromotive force expressed by the quotient of the entire resistance divided by the resistance E Q′. For less electromotive forces the switch N is swung so as to connect with D or with C.

Current Measurement with the Potentiometer.—The current is passed through a standard low resistance. The drop between its ends is determined by connecting branches from its ends at E. Knowing the drop and the resistance in which such drop occurs, the current is calculated by Ohm's law $I = \frac{E}{R}$.

To determine resistance by the potentiometer, the conductor under trial is put in series with a known resistance, and a battery is connected in the circuit. The potential difference between the ends of the known resistance is determined, which depends on

the current strength. The potential difference between the ends of the conductor under trial is next determined. As the current strength is supposed to be the same as before, the resistance of the conductor is determined by the relative drop.

Should there be any apprehension that the current strength has

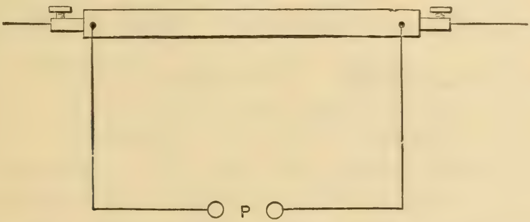


FIG. 488.—RESISTANCE DETERMINATION BY POTENTIOMETER.

changed between the two determinations, it is only necessary to make new determinations, and if there is only a slight difference the average may be taken. In order to secure a virtually constant current put good resistance in series with the battery and two working resistances.

The connection is shown in Fig. 488.

CHAPTER XXXVI.

ELECTRICAL ENGINEERING MEASUREMENTS.

Voltmeter Measurement of Resistance.—The following is a quick method of measurement with simple appliances. A known resistance and voltmeter are all that are needed.

Referring to the diagram, Fig. 489, D E is a source of current supposed to be constant during the time of the experiment, r is a known resistance, and R is an unknown resistance, which is to be determined. The voltmeter V is first placed across the terminals of one resistance, say of r, as shown, and its deflection giving the drop or voltage is noted. It is then connected across the other resistance—in this case it would be the unknown one R—and its deflection also noted. Suppose that for R the deflection is E, and for r is e. We then have $E : e :: R : r$, or $R = \frac{r\,E}{e}$

Voltmeter and Ammeter Determination of Resistance.—Suppose that we have a voltmeter and an ammeter, but no known resistance. Then we place the ammeter in circuit with the unknown resistance, and then connect the voltmeter across the terminals of the unknown resistance. The diagram, Fig. 490, shows the connections. E is the source of current, A is the ammeter, V is the voltmeter, and R is the unknown resistance. By Ohm's law we have $R = \frac{E}{I}$. The ammeter reading gives I, the voltmeter reading gives E; the quotient of E divided by I gives the resistance of the conductor R in the diagram.

Low-Resistance Measurements.—With a milli-voltmeter low resistances can be measured by the above method. The diagram, Fig. 491, shows it applied to measuring the resistance of the armature of a dynamo or motor.

The terminals from the circuit containing the source of cur-

rent E and ammeter A are connected to opposite bars of the commutator through the brushes, or directly by being pushed under the brushes between them and the commutator bars. With the milli-voltmeter *m* V connected as shown, the resistance of the armature can be measured, using the formula given in the last example.

High-Resistance Measurements.—For high-resistance measurements the plain voltmeter may be used. Its resistance must be known, and figures as the known resistance *r*. The diagram.

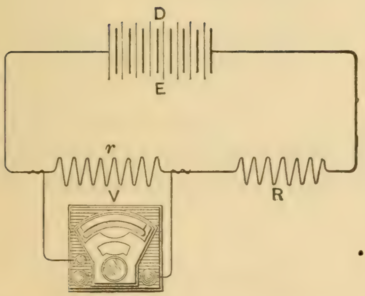


FIG. 489.—VOLTMETER DETERMINATION OF RESISTANCE.

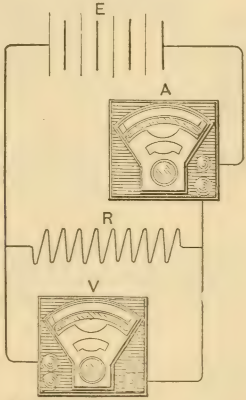


FIG. 490.—VOLTMETER AND AMMETER DETERMINATION OF RESISTANCE.

Fig. 492, shows the arrangement of the apparatus. E is the source of current, R is the unknown resistance, V is the voltmeter of the resistance *r*, and K is a switch. The voltage E through *r* is given when the switch is closed; the voltage E′ through R + *r* in series when the switch is open. E is greater than E′. The unknown resistance R is given by the formula

$$R = r \frac{E - E'}{E'}$$

Line Insulation Tests.—The above method as applied to an active high-potential line to determine its insulation, is shown in

Figs. 493 and 494. It is used to detect a ground. The voltmeter is connected with one terminal grounded first to one lead and

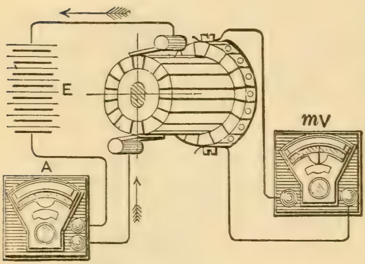


FIG. 491.—DETERMINATION OF LOW RESISTANCE WITH VOLTMETER AND AMMETER.

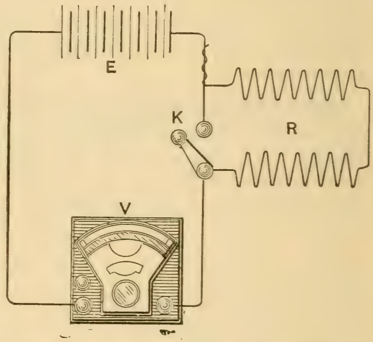
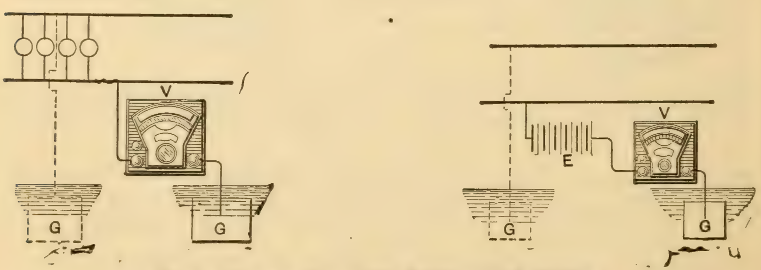


FIG. 492.—VOLTMETER MEASUREMENT OF HIGH RESISTANCE.

then to the other line. If the line is dead, a battery can be put in circuit with the voltmeter. Let E be the difference in potential between the lines, and E′ the difference in potential between one



FIGS. 493 AND 494.—LINE INSULATION TESTS.

line and the ground. Then calling R the line insulation and the known resistance of the voltmeter, we have:

$$R = r\frac{E - E'}{E'}$$

Rail - Joint Test.—The resistance of rail joints is an impor-

tant factor in electric railroad practice. With a sensitive galvanoscope, such as a milli-voltmeter, reflecting galvanometer, or telephone receiver, it can be determined thus:

Wires are secured to the rail just over the ends of the bond, or within a short distance of the joint and inside the limits of the bond. They are connected to the galvanoscope as shown in Fig. 495. The rail joint represents one arm of a Wheatstone bridge, the wire A B represents another arm, and the cross connection is made up of the galvanoscope and the two wires connected with it. From the point B another wire is taken, and is moved along the rail on the other side of the joint until nc

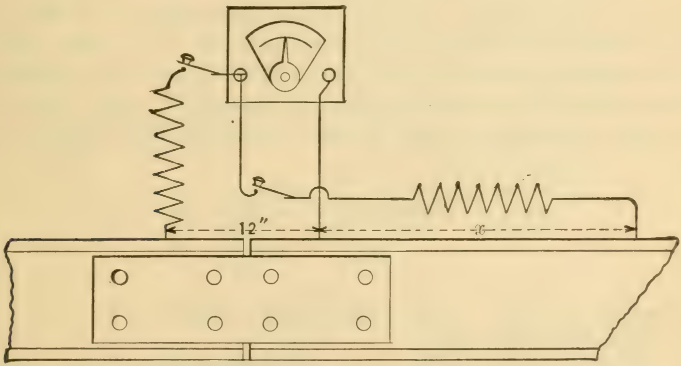


FIG. 495.—RAIL JOINT TEST.

sign of current can be discerned in the galvanoscope. By the principle of the Wheatstone bridge the resistance of the joint is equal to that of the portion C D of the rail. Twelve inches is a usual distance for the space including the joint. The current passing in the rail from the operation of the road is the current which is used in the experiment. It may be necessary to protect the galvanoscope by resistances. If so, they must be placed as shown. A couple of keys as indicated are convenient also. The resistance of the joint is expressed as $\frac{CD}{AD}$. This gives the length of rail equal in resistance to a joint.

Measurement of Insulation Leakage.—An insulated electric

cable represents a condenser or Leyden jar. The insulation is the dielectric, or a part of it. If the cable is an aerial one, the air is also part. If the cable is sheathed, the metal sheathing represents the outer coating. Otherwise the earth or moisture on the cable may be representative of the outer coating. The inclosed conductor represents the inner coating. It can be charged just like any condenser. A definite quantity of coulombs or microcoulombs of electricity at a definite potential can be charged upon the metal surface of its conductor if both ends are disconnected from everything, leaving the conductor insulated. If so charged and left to itself, the charge will slowly leak out, owing to imperfect insulation. The resistance of the insulation determines the time. The value of the insulation in megohms, R meg., per mile is given by the following formula. In it C is the capacity in microfarads per mile of the cable, E the potential of charge at the beginning of a certain number of seconds T, and e the potential at the expiration of that period. Then the resistance is given by

$$\text{R meg.} = \frac{26.06}{\text{C} \log \frac{\text{E}}{e}}$$

Insulation leakage varies with this resistance, which is called the insulation resistance.

Insulation Resistance of a Metal-Sheathed Cable.—This is the resistance between the wires and the sheath in a given length of cable. If it contains a quantity of wires, they are bunched at one end for the test, or for special purposes the wires may be tested individually. The diagram, Fig. 496, gives the theory of the connections. One wire is connected to the sheathing of the cable, one is connected to the bunched end of the wires; a special switch V is in parallel with the galvanometer G and shunt S. Thus the connections are the same as in a Wheatstone bridge, with the exception that the switch has been introduced, and that the insulation between wires and sheath in the cable takes the place of the unknown resistance of the bridge. A battery B and known resistances O and R complete the system.

Before closing the circuit by connecting the wire to the cable

sheath or bunch of wires, the switch K is closed. Then the connections are completed, and the battery charges the cable. This sudden rush of current does not affect the galvanometer, as it goes almost entirely through the switch. The switch is now opened, and the galvanometer deflection, after it has stood a few minutes, is noted. To keep the deflections within proper limits, the shunt S may have to be adjusted. The battery must give the voltage used in determining the constant.

If the same shunt has been used as was employed in determining the constant, the galvanometer constant divided by the

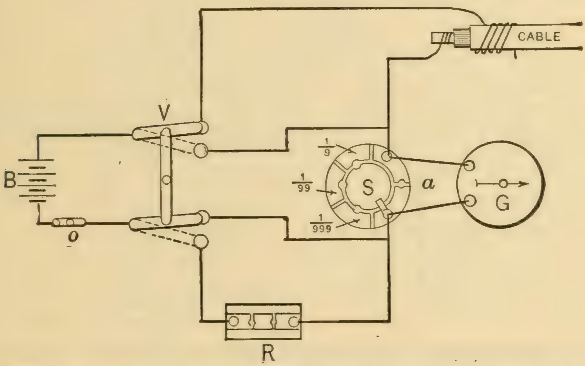


FIG. 496.—INSULATION RESISTANCE OF A METAL-SHEATHED CABLE.

deflection gives the meg-ohms resistance of the insulation of the cable tested. If a different shunt has been employed, multiply the result by the multiplying value of the original shunt and divide by the multiplying value of the shunt used in the test.

The first deflection of the galvanometer is not noted. An extra quantity of electricity flows into the cable at first. After standing a minute the reading is generally assumed to be correct. The slow absorption of electricity is termed electrification.

Suppose that with a galvanometer shunt of $g/999$, the constant of 25,000 was determined, and that using the same constant and of course the same voltage on a cable insulation, the galvanometer deflection was too small to be accurately read. Suppose the gal-

vanometer shunt had to be changed to $g/99$ and that a deflection of 55 resulted. The insulation resistance would be $\frac{2500}{55} \times \frac{1000}{100} =$ 454.6 meg-ohms.

What is wanted is often the meg-ohms of insulation resistance per mile. In such case the meg-ohms found are multiplied by 5,280 and divided by the length in feet of the piece of cable tested.

Telephone cables show from 1,500 to 2,500 meg-ohms per mile.

Determination of Capacity of a Cable.—When the capacity

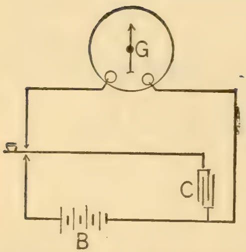


FIG. 497.—CAPACITY TEST.

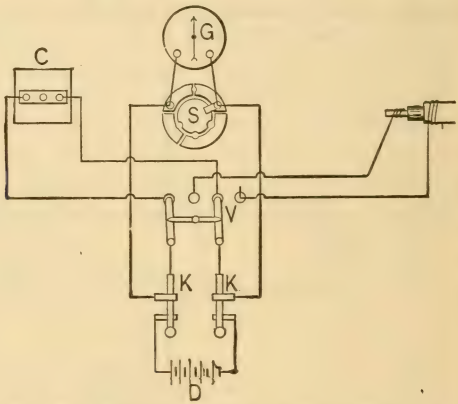


FIG. 498.—DETERMINATION OF CAPACITY OF A CABLE.

of a cable is to be determined, the ballistic galvanometer is used, and a standard condenser. A galvanometer shunt will ordinarily be needed unless the standard condenser and line to be tested have capacities rather close together.

The cut, Fig. 497, shows the determination of the throw due to a standard capacity, which for telephone cables would be about 1/10 microfarad. Seven or eight cells of battery may be used. C is the standard condenser, B the battery, G the ballistic galvanometer. On depressing the key the condenser is charged; 15 or 20 seconds may be allowed for this. Then the key is suddenly released, and it springs upward and connects the galvanometer to the terminals of the condenser. The latter discharges its charge

through the galvanometer, and the deflection, which is an instantaneous throw only, is noted. Next for the terminals of the condenser are substituted connections to the wire in a cable and to the outer metallic sheathing of the same. The distant ends of the wires are disconnected from the sheath and from the ground. The operations are repeated, and the throw of the galvanometer is again noted. The throw due to the discharge of the cable is divided by that due to the discharge of the condenser, and the quotient is multiplied by the capacity of the condenser. The result is the capacity of the cable.

The connections for a capacity-testing apparatus are shown in the cut, Fig. 498. G is the galvanometer, S its shunt, C the standard condenser, V a double-pole switch, K K discharging switches, and B the battery.

The switches K K are depressed on their lower connections. This brings the battery in circuit with the condenser. The latter should be arranged so that various capacities can be obtained from it. The battery now is allowed to charge the condenser for 15 or 20 seconds, when the keys K K are released and the throw of the galvanometer is noted. The double-pole switch V is now thrown to the right. This substitutes the cable to be tested for the condenser. The switches K K are again depressed for 15 or 20 seconds and suddenly released, and the throw of the galvanometer again noted.

If the shunt had to be used, the multiplying power used for the cable is divided by that used for the condenser, and the figure obtained as described on page 648 is multiplied by this quotient to get the capacity of the cable.

The capacity of a cable affects its use in telephony; the greater its capacty, the more poorly will it work. An interesting application of the test is involved in the determination of a break in the conductor of a cable. It is only applicable in cases where there is high insulation resistance—a meg-ohm at least.

The capacity of the broken wire or conductor is determined first from one end of the cable, and then from the other end. It is perfectly evident that the capacities of the two parts will vary as their lengths. A simple proportion will give the lengths.

Thus, call x the distance to the break from one end, and K the

capacity of this part, K′ the capacity of the other part, and $a - x$ the distance to the break from the other end. Then we have the proportion:

$$K : K' :: x : a - x$$
$$K' x = K a - K x$$
$$(K' + K)\ x = K a$$
$$x = \frac{K a}{K' + K}$$

If there is a good wire in the cable, this can be used to avoid the necessity of carrying the instruments from end to end of the line. Deflections are obtained, d for the near section of broken wire, d' for the good wire, and d'' for the good wire connected to the distant broken section, which last gives the sum of the deflections due to the good wire's and distant section's capacities. Hence the capacity of the two sections of broken wire is $d'' - d' + d$. As before let x be the length of the near section and a the total length of the wire. Then the deflections being proportional to the capacities, and consequently to the lengths of the wires, we have:

$$d'' - d' + d : d :: a : x$$
$$x = \frac{a\ d}{d'' - d' + d}$$

If there is low insulation resistance, this test is inapplicable. If the capacity of the cable per mile or other unit of length is known, a determination of the capacity of the near section gives the requisite datum in combination with what is known to calculate the location of the break. Thus, call the capacity of a mile of submarine cable K, and that of the broken section K′. It is evident that the length of this section is equal to $\frac{K}{K'}$. As before, the deflections may give it directly if those due to capacity K are known. As K′ might be due to many miles or only a few, the galvanometer shunt might have to be used, and possibly different galvanometers for extreme cases. This would introduce simple multiplication factors or divisors into the calculation.

Galvanoscope Cable and Line Tests.—An uncalibrated galvanometer with three or four cells of battery is useful for testing

lines for grounds, crosses, or breaks. One terminal of the battery is grounded, the other end is connected to the end of the line to be tested, which must be on open circuit at the near end. The galvanoscope will be apt to move at the instant the connection is made. Suppose that the distant end of the line is on open circuit also. A permanent deflection of the galvanoscope will indicate a ground. Suppose there is no deflection. Then as the line has shown no ground, the distant end is to be next connected to earth. If the galvanoscope shows a permanent deflection, the line is continuous and without ground. But if the galvanoscope shows no deflection on the second test, the line is broken somewhere, and the part beyond the break may be full of grounds. The break prevented them showing on the first test.

If on the first test the galvanometer gives a strong throw of the needle, followed by a return to zero, it goes to prove that the line is continuous, as this throw is due to the capacity of the line, and the capacity is greater as the line is longer. But there is nothing accurate about this test. If the observer knows the line and knows the instrument, he may draw a useful conclusion from the observation of the first throw of the needle. Such conclusions are on a par with those which an observer draws from the loudness of the ring of his magneto bell.

With a galvanometer and battery, all the wires in a cable can be rapidly tested for crosses, by connecting across from one to another seriatim or in succession. Thus one wire can be connected through the galvanometer and battery to all the others bunched. The distant ends of the wires in the cable are supposed to be disconnected or on open circuit. If no permanent deflection is shown, one wire is shown to be all right, and without cross connection with any of the others. This wire is bent aside, tagged or marked if desired, and the end of another wire pulled out of the bunched ends, and is tested against the rest of the wires. This time there is one less wire in the bunch than before. If the wire is without cross, it is put aside and another tested. Eventually, only a pair will be left to be tried, one against the other, if no crosses have been found. A cable full of wires can be rapidly gone through. If a ground is found, it will be between the single wire and one or more of those left in the bunch. By

testing one wire after another out of the bunch against the crossed wire, the fault can be located as far as the specific wires are concerned. The two or more wires which are crossed can be found and tagged or marked, so as to exclude them from the working wires of the cable.

Frequently the testing is done to cables while rolled up on the wooden reels on which they are transported. The cable on a reel is tested and found perfect, and is then drawn into the duct in the conduit. Wires found defective should be tagged with the indication of their defect, whether grounded, crossed, or broken.

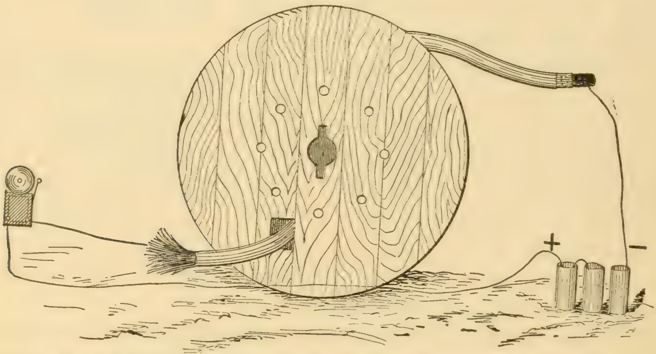


FIG. 499.—CABLE TESTING ON REEL FOR BREAKS IN WIRES.

Cables are supposed to be subjected to severe tests by the manufacturers, so that new cables are often assumed to be perfect, and no test is applied by the purchasing company. There are two possibilities. One is that the cable has been injured in transportation; the other is that it may be injured in being drawn into the duct.

Tests of Cable on Reels.—When cables are still on reels, both ends are accessible, and they can be conveniently tested. The cut, Fig. 499, shows the connection for finding breaks of continuity in individual wires of a cable. The bunched ends of the wires at one end are connected to a battery and galvanoscope. The other end of the wire of the circuit is touched to the other ends of the cable wires, one by one. These ends are opened so as

not to touch each other. As shown in the cut, a bell is used as galvanoscope. A ringing will indicate that there is no break in the wire which is touched. The test for crosses should also be made.

Finding Wire Ends in a Cable.—It will be seen that similar tests can be applied to picking out the two ends of a wire in a cable. The distant end of the wire is grounded. The near end of one wire after another is connected through the battery and galvanometer to the ground, until the galvanometer shows the existence of a current.

Making Branch Connection in a Cable.—Sometimes it is desired to take a branch line from an intermediate point in a cable. The above test can be applied to pick out a wire from the cable whose sheathing has to be opened for the purpose of making the connection. The distant end of a wire is grounded. The wires are loosened or opened. Connection of one wire after another is made with the galvanometer and battery which are grounded. The connection is made by means of a pointed wire or needle point, which forms the terminal of the wire from the battery and galvanoscope. This is thrust through the insulation of one wire after another in the opened part of the cable, until the indications of a current on the galvanoscope show that the right wire has been found.

The Telephone as a Galvanoscope.—The telephone, whose diaphragm gives a sharp click upon making or breaking an active circuit of which it forms a part, is an exceedingly sensitive indicator of current. It can be substituted in many cases for a galvanometer, being connected in series with three or four cells of dry battery. Portable sets are made for this purpose, comprising a pocket battery and small telephone. Where much testing is to be done, a strap or spring should be used to hold the telephone against the ear of the observer. Otherwise, where perhaps a hundred wires in a cable have to be tested, the work of holding the telephone by hand will become quite laborious. The telephone and battery represent the combination of hand magneto and bell. The test is made by touching and separating the end of a wire in the circuit to the telephone terminal, or by otherwise suddenly making and breaking the current. Due regard must

be had to capacity of the wire. A click in the telephone will be produced by this alone if it is at all considerable.

The following method of using the telephone test for crosses and grounds in a cable is given in Roebling's pamphlet on telephone cables. It may be applied most conveniently to cable on the reel, as both ends are then accessible from the observer's position. At the near end of the cable the wires are spread a little, and the particular wire under test has a short piece of wire connected to it. The rest of the wires are bunched, and by a short piece of bare wire are connected to the sheath of the cable. The arrangement and connections are shown in Fig. 500.

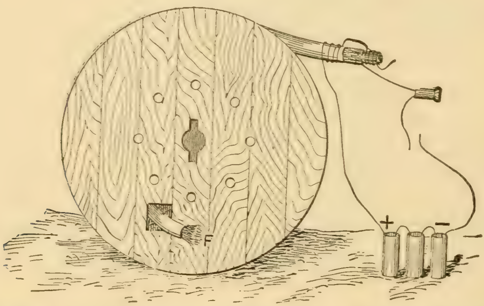


FIG. 500.—CABLE TESTING ON REEL FOR SHORT CIRCUITS.

By a short piece of wire one terminal of the battery is connected to the cable sheath. The other terminal of the battery is connected with the telephone. The observer holds in his hand the end of the wire, which is connected to the wire to be tested. He suddenly taps with it one of the binding posts of the telephone. This gives it a charge of electricity, and if it is not crossed or grounded, which means connected to the lead sheath of the cable, a click will be heard in the telephone. This tells nothing. But if the wire is in good condition as regards crossing and grounding, it will hold its charge, and on a second tap being given the telephone will give no sound or a greatly diminished one, and a third tap will be almost sure to produce no sound whatever. But if the wire is crossed or grounded, a

closed circuit will result from each tap. The circuit will include the telephone, battery, sheath, and wire, and perhaps another wire or wires if there is a cross; consequently, in such a case every tap will give a click on the telephone.

If no click is given on the first tap of all, it will indicate that the wire is broken off, probably close to the observer.

Even moisture in the cable will impair the insulation enough to give the indications described. The loudness of the click will give some clew to the extent or degree of the trouble.

It will be seen that the test for continuity of the wire is a part of the test for crossing and grounding. The telephone can be

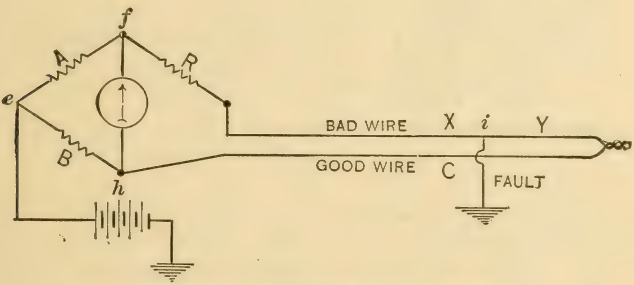


FIG. 501.—VARLEY'S LOOP TEST.

used for it. A continuous clicking, as the telephone terminal is tapped, represents a permanent deflection of the needle of the galvanoscope.

The Vibrating Magneto Bell as a Galvanometer.—A vibrating bell can be used in tests where a galvanometer is applicable. Three or four cells in series with it give the current. It is very convenient for continuity tests.

Some of the tests just given are not quantitative—which means that no measurement of current, resistance, or other function is executed. An idea of the degree of trouble with a cable can be obtained from the indications of the instruments, but that is all. Experience will teach the observer to place the right amount of dependence, rather little than much, upon differences of degree which have been alluded to.

Varley Loop Test.—This is an application of the Wheatstone bridge. Suppose that there is a bad wire in a line, as shown in Fig. 501. Its distant end is connected to the end of a good wire, and the two are connected into a Wheatstone bridge, as shown. The battery is grounded as shown; the points *i* and *e* represent the ends of the bridge, R + X is the resistance of one arm of the bridge; C + Y is that of the other. We have as the equation of the bridge:

$$\frac{A}{B} = \frac{R + X}{C + Y}$$

The entire resistance of the two wires is equal to X + Y + C. Calling this resistance L, we have:

$$L = X + C + Y \text{ and } L - X = C + Y.$$

Substituting L — X for C + Y in the first equation, we have:

$$\frac{A}{B} = \frac{R + X}{L - X} \text{ and } X = \frac{A\,L - B\,R}{A + B}$$

If the resistance A is equal to B, we have:

$$X = \frac{L - R}{2}$$

If L is known, X can be determined; L is found by calculation from the size and length of the wires or from records. If there is only one ground, it can be measured by bridge connection, the battery terminal being taken from the ground and connected between R and X.

Hand Magneto Tests.—The hand magneto is a bipolar generator with shuttle or H-section armature. The latter is rotated by multiplying gear, and the current is taken off by two contact rings.

It is made in stock size, and is in itself a rough measuring instrument. A bell is mounted in the box, whose armature is polarized and is acted on by an electro-magnet. The winding of the magnet is in circuit with the armature winding of the magneto. On turning the handle, the bell will ring if its circuit is closed. The diagram, Fig. 502, shows the connections.

The hand magneto is much used in testing insulation. One terminal may be connected to a line to be tested, and the other terminal to a water or gas pipe to give a good ground. On turning the handle, the bell will ring if the insulation of the line

is defective within the limits of the sensitiveness of the instrument. The magneto in question with its bell is generally so wound that the bell will ring through 20,000 to 25,000 ohms.

By practice and use of the same magneto, the operator using it can roughly approximate to the seriousness of a ground, or to the resistance of the circuit rung through, if he notes the loudness of the bell and the clearness of its ring. It is dangerous to rely too much on such indications.

Hand Magneto Test for Ground.—If a line or cable is to be tested for grounding, the circuit is opened at both ends. The

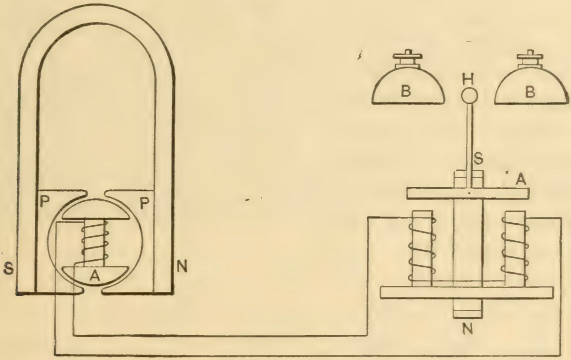


FIG. 502.—HAND MAGNETO AND BELL FOR TESTING.

practical point is to be sure that the far ends of the line wires are on open circuit. The near end is opened, connected to the magneto, and the other end of the magneto circuit is grounded. If the bell rings on turning the handle, the assumption is that there is a ground.

But simple as this test seems, it is not reliable. The alternating current produced by the magneto may, by charging and discharging an ungrounded line of some capacity, ring the bell and so lead to false conclusions. This test is of great use where the line is of slight capacity, which is the case with a bare wire on poles. But cables with metal sheathings represent a sort of Leyden jar, and may ring the bell when there is no ground upon them.

Hand Magneto Test for Cross Connections.—To test for a cross connection in a cable, one terminal of the magneto is connected to the wire to be tested, and the other to the ends of the remaining wires, which are bunched for the purpose. If the bell can be rung, a cross is present. The test can be applied if desired to a single pair of wires, so as to go through the cable wire by wire instead of bunching all except the one.

Engineering Tests.—The distinction between engineering and laboratory tests and measurements is definite. Much apparatus is used in laboratory work which it would be quite impossible to employ in outdoor work in the streets of a city. Any tendency to the refinement of what may be called street tests is accompanied by a corresponding tendency to apply the finer processes of the laboratory to more and more of the every-day problems which confront the engineer. It is therefore a fair conclusion that the distinction between the two classes will always exist. The object of the engineer should be to use the finest class of measurements in his work, and to constantly appeal to the laboratory for final data.

CHAPTER XXXVII.

ELECTROPLATING.

Elec'roplating.—The decomposition of a metallic salt by the electric current in such a way that the metal is deposited where desired constitutes electroplating. To deposit metal, a current must pass through the solution by electrolytic conduction. This gives the general case without reference to electrons or to the ionic theory. The latter only affects the theory of the case.

Energy Absorbed in Electroplating.—The rate of expenditure of electric energy is expressible in volt-amperes or watts. To deposit metal some current must pass through the solution, because each coulomb precipitates a given and invariable amount of each metal. Until some current passes, no metal will be deposited. If the current passing through a given bath be multiplied by the voltage required to force the current through the bath, the rate of energy will be given in watts or volt-amperes.

The voltage may be derived from an outside source, such as a battery or dynamo, or part or all of it may be derived from the bath and its electrodes. A Daniell's cell is an example of a plating bath, which deposits copper upon a surface of copper, the reaction between the electrodes and solution producing all the required voltage. If copper electrodes are immersed in a bath of copper sulphate and a current is passed through the solution, all the voltage is derived from an external source. In other cases the solution and electrodes may generate part of the voltage only, the rest being supplied from an external source.

General Principles.—The general principle is easiest fixed on the mind by reference to the primary battery. If from the terminals of such a battery wires are led to a bath filled with a plating solution, and if the ends of the wires are attached to objects of metal adapted for the purpose, and if the metal objects

are immersed in the bath, electro-deposition of the metal of the bath will take place, and the object connected to the zinc plate of the battery by the wire will have metal deposited upon it. The one attached to the copper, carbon, or platinum plate of the battery will have no metal deposited on it, and in many cases will be dissolved in the bath, and gradually disappear.

Anodes.—The plate on which no metal is deposited is called the anode. Thus, for nickel-plating nickel anodes are a regular article of commerce. They are dissolved in the nickel bath in the course of the plating operation. For each ounce of nickel deposited, an ounce should be dissolved. There are other terms, such as cathode, for the plate on which metal is deposited, which have never come into general use.

Reproduction.—Electroplating is used for two purposes. One is to reproduce objects. To do this, a mold is taken from the object. This mold may be of wax, papier maché, fusible metal, or any substance which can be made to give a reversed reproduction of the object. A thick layer of metal may be directly electroplated on the object. This layer peeled or stripped from the original gives a reversed reproduction. On such the metal is deposited, which on removal obviously gives the direct unreversed reproduction of the original object. The other purpose is to coat one metal with another, as spoons and other table ware are coated with silver.

Current for Electroplating.—A source of heavy current and of low voltage is required for electroplating. If a battery is used, it is a low-resistance battery. The amperes required are generally found by determining the area to be plated, and allowing a definite amperage to each square inch or other unitary area of the articles. A solution is contained in a vessel, which is called the bath. The objects to be plated are immersed in it, and opposite to them are the anodes. The wire from the zinc pole of the battery, if such is used, or from the corresponding pole of the dynamo, is connected to the objects. The other wire is connected to the anodes. As current passes, the metal is deposited. The voltage varies for different solutions. From one to ten volts is a good range. It must be noted that a high voltage does no harm as long as the current is of proper strength, but the voltage must

be high enough to produce the requisite current and to decompose the solution.

Regulation of Current.—The strength of current is regulated by adjusting the resistance in the circuit. A simple resistance frame, such as is shown in Fig. 503, is often used for this purpose. As the handle is swung in the direction indicated by the arrow, it cuts in less resistance.

Simple Plating Apparatus.—Electroplating on the small scale is often done by the amateur with apparatus on the lines of the Daniell battery, Fig. 504. The object to be electroplated or reproduced takes the place of the copper electrode, and is attached by a wire to the zinc electrode. If the object is of a metal electro-negative to zinc or is coated with plumbago, copper will be deposited on it. Fig. 505 shows a circle of porous cups in a circular tank containing zinc plates, all connected by a circle of wire. A metal cross rests on the circle, and carries at its center the object to be plated. The large tank contains copper sulphate; the porous cups, water with a little salt.

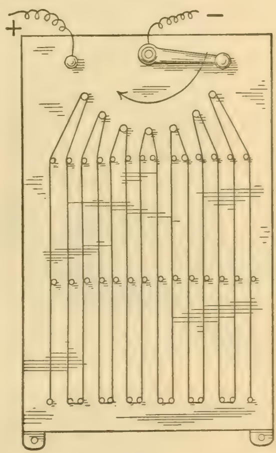


FIG. 503.—ELECTROPLATER'S RESISTANCE FRAME.

Large Plating Apparatus.—The illustration, Fig. 506, shows a bath for electroplating, around whose upper edge two frames of metal run. The outer frame is a little higher than the other. Long rods rest upon the outer frame, and the anodes are suspended from them, and short wires rest on the inner frame. The objects to be plated are suspended from these wires. One frame is connected to one pole, the other to the other pole of the battery or other source of current. The next cut, Fig. 507, shows a plating bath A and battery D.... There are two main wires or bus-bars, *a b* and *c d*. One has the anodes K K connected to it by transverse wires *m m;* the other has the objects connected

to it. One battery pole is connected to one bus-bar, the other to the other. Insulation is applied to the wires where required to prevent short circuits.

Metals Deposited.—Copper, nickel, silver, and gold are the metals generally deposited.

Copper-Plating.—The bath, for objects not attacked by sulphuric acid or copper sulphate, may be a solution of copper sulphate with one-tenth of its volume of sulphuric acid. It should have a density of 1.197, and is used cold. If the bath contains too much copper sulphate, this will form crystals on the surface of the

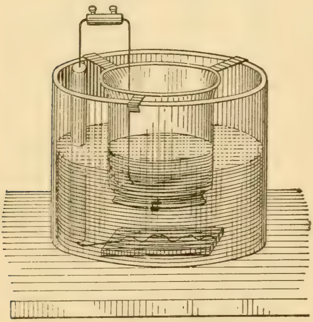


FIG. 504.—DANIELL'S BATTERY PLATING APPARATUS.

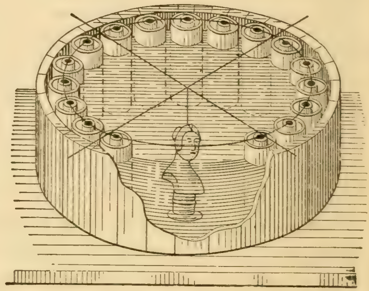


FIG. 505.—LARGE DANIELL'S BATTERY PLATING APPARATUS.

anode. Such crystals, perhaps invisible, will prevent the passage of current. This bath is of limited application, as it cannot be used for iron or zinc. It is applicable to wax molds, such as are used in electrotyping.

For depositing copper on zinc and similar metals, the following baths are applicable: Copper sulphate, 2 pounds; water, 1 gallon. Add ammonia until the precipitate first formed is just redissolved. This colors the solution blue. Then add potassium cyanide until the blue color disappears. This bath should be used at a temperature of 122° F. to 131° F. (50° C. to 55° C.).

If zinc is to be plated, the piece is first dipped into a mixture of 4.5 per cent sulphuric acid, and then after washing into a solution

of caustic soda or of sodium carbonate. It is then ready for plating.

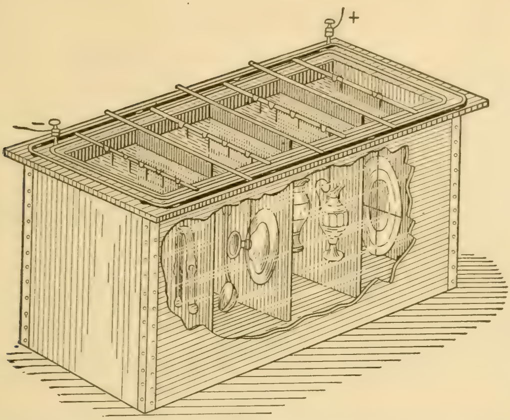


FIG. 506.—ELECTROPLATER'S BATH.

Electroplating such metals as iron or zinc is only to be recommended for special purposes. On any water getting at the zinc or iron, galvanic action commences and the metal is attacked.

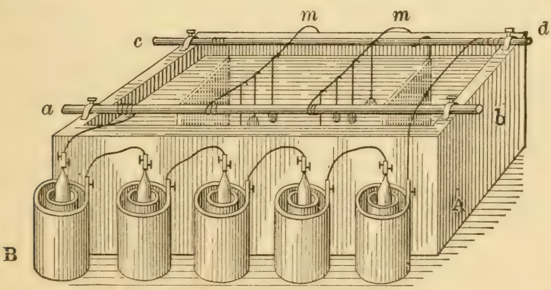


FIG. 507.—ELECTROPLATING APPARATUS.

In Paris copper-plating has been applied to lamp-posts for the streets, they being first varnished, or coated with oil mixed with copper powder. It is not a perfect success.

One case in which iron may be copper-plated with advantage is when the metal is to be silver- or gold-plated, and a preliminary copper-plating is often recommended as a preparation for nickel-plating on iron.

Copper and potassium tartrate and copper and ammonium oxalate are bases of the formulas.

Before copper-plating iron, it should be dipped in dilute sulphuric acid, and then after washing into an alkaline solution, as prescribed for zinc.

Nickel-Plating.—The following are formulas for nickel-plating baths with sulphates as the base:

Ammonium and nickel sulphate...	4 parts	1 part
Distilled water	100 parts	10 parts
Ammonium carbonate (about)....	3 parts	

The double sulphate as above is a salt very much used in nickel-plating.

The chloride may also be a basis for nickel-plating as in the following formula:

Nickel chloride	298 parts
Water	2250 parts

Dissolve and add

Ammonium chloride	70 parts
Water, enough to make.....................	10,000 parts

Edward Weston recommends the addition to nickel-plating baths of boric acid—2 parts of boric acid to 5 parts of nickel chloride or 1 part of boric acid to 3 parts of nickel sulphate.

Too much alkali in a nickel bath gives a yellow deposit; too much acid gives a non-adherent coat. The bath must be perfectly neutral. The bath should have a specific gravity of 1.041 to 1.056. If it is weaker, the bath works slowly; if stronger than specific gravity 1.070, salts crystallize on the anodes. The bath must be constantly watched for changes in its specific gravity.

The pieces to be plated must first be polished, the last polishing being given with powdered lime. The pieces are cleaned of grease with a 10 per cent solution of caustic potash. They are sometimes scrubbed with a brush in a mixture of warm water, Spanish white, and sodium carbonate. Sometimes benzine is used to remove grease.

If copper is to be nickel-plated, it is first dipped into a 10 per cent solution of nitric acid, and after washing is dipped into a solution of 5 parts of potassium cyanide in 100 parts of water.

For iron the first acid dipping bath is a 1 per cent solution of sulphuric acid. The pieces are rubbed with powdered pumice stone, and then dipped in a 20 per cent solution of hydrochloric acid. Iron objects must at once be put into the bath after treatment; otherwise they will rust. A thin plating with copper may precede the nickel-plating.

Zinc can be nickel-plated by receiving first a good coating of copper, or it may be amalgamated. The latter tends to make it almost as brittle as glass.

On removal from the bath nickel-plated objects are first washed in cold then in hot water, and are dried in wood sawdust. They are polished by regular processes.

Nickel anodes must be chemically pure; they are suspended by nickel wires. Their surface area must be a great deal larger than that of the objects to be plated, because the solutions dissolve nickel with difficulty. It is a great object to have the anode dissolve exactly as fast as the metal is deposited. If this occurs, the solution remains of unvarying strength.

The voltage to be used varies. It may start as high as 5 volts, and is to be reduced when the piece appears white, and may eventually run down to 1 volt. The evolution of hydrogen must be kept down as much as possible, although there is always more or less of it. Change of relative position of the anodes and pieces to be plated is often advisable, to prevent the deposition concentrating itself on salient parts.

Silver-Plating.—Baths for silver-plating are generally made of potassium-silver cyanide. Pure silver nitrate is the starting point for this preparation. The following are examples of silvering solutions:

A solution of silver nitrate in water is precipitated by addition of lime water, the silver oxide appearing as a brown powder. The precipitate is washed with care, and is kept in vessels full of water. To prepare a bath for plating, some of the brown oxide is dissolved in solution of potassium cyanide in distilled water.

A solution of silver nitrate may be precipitated by solution of

potassium carbonate, or of sodium chloride (salt), and treated as above.

332 parts of silver nitrate are precipitated by hydrocyanic acid. The acid must be made immediately before use by adding nitric acid to potassium cyanide in quantity just sufficient to neutralize it. The precipitate is washed and put into 10,000 parts of water, and dissolved by addition of potassium cyanide.

One or two thousandths of ammonia added to a bath improves the adherent power and brilliancy of the deposit. A very small quantity of carbon disulphide is sometimes added for the purpose of securing a bright deposit.

To obtain an even deposit, the pieces in the bath must be moved about. This is sometimes done mechanically. The anodes are of pure silver, and their surface should be about equal to that of the pieces to be silvered. Iron or lead wire is used to hang them by. Copper wire must not be used, as it would dissolve and injure the solution by introducing copper into it.

At least 4 inches space must be between the anode and the pieces to be plated. On commencing, a current of 42 to 43 amperes per square yard of surface to be plated is required. A potential of not over 2 to 3 volts is also prescribed, although it is to be remembered that as long as the voltage is sufficient, the amperage is the critical thing in electroplating. After a quarter of an hour in the bath the pieces are taken out and examined to see if they are acquiring a uniform coating. They are then washed in a warm solution of potassium cyanide and replaced in the bath, and left there until the plating is thick enough for the requirements. Four hours should complete the operation if there is enough current. Every 3600 coulombs or each ampere-hour deposits 62.4 grains of silver.

When the deposition is completed, the pieces are removed from the bath, washed with clean water, and then with water slightly acidulated with sulphuric acid. They are finally brushed and polished by the regular processes.

Preparation for Silvering.—Preparation of articles to be silver-plated begins with the removal of grease by boiling for a few seconds in a ten per cent solution of caustic potash. This is followed by washing in water and then dipping in a ten per cent

solution of sulphuric acid and water and washing. Next they are passed through a bath composed of

Nitric acid (36°)	100 parts
Salt (sodium chloride)	2 parts
Calcined lampblack	2 parts

After a few seconds they are washed vigorously, and then are passed at once through this bath:

Nitric acid (36°)	600 parts
Sulphuric acid (66°)	80 parts
Salt (sodium chloride)	4 parts

Again they are vigorously washed and placed in the "quicking" bath until they appear white on the surface. This bath is made up of:

Water	100 parts
Mercuric nitrate	1 part

With enough sulphuric acid to dissolve the mercuric nitrate. The pieces are then washed and put into the plating bath.

Gold-Plating.—Gold-potassium cyanide is used for the bath. 154 parts of gold chloride are dissolved in 2000 parts of water. A separate solution of 200 parts of potassium cyanide in 8000 parts of water is made. The two solutions are mixed and boiled for half an hour.

This bath is employed at the ordinary temperatures. To keep up its strength, gold chloride and potassium cyanide may be added in equal parts as needed. The anode is a plate of gold. A bath too rich in gold gives a blackish or reddish coating. A gray coating slowly formed indicates too much potassium cyanide. Platinum suspension wires are employed for the anode. The anode should not be left in the bath except during the plating.

For gilding with a warm solution the following baths may be used:

	1.	2.
Sodium phosphate (crystallized)	600 parts.	500 parts.
Sodium bisulphite	100 parts.	125 parts.
Potassium cyanide	10 parts.	5 parts.
Gold chloride	12 parts.	12 parts.

The first formula is for gold-plating silver, copper, and alloys rich in copper. The second formula is for iron and steel.

The sodium phosphate is dissolved by heat in 8000 parts of water, the gold chloride in 1000 parts of water, and the two solutions are mixed. The remaining salts are dissolved in 1000 parts of water and added to the others. This gives nearly 10,000 parts of solution by weight, or about a one-tenth of one per cent solution of gold cyanide.

These baths are employed at temperatures of 122° to 176° F. (50° to 80° C.). A few minutes is time enough to give a coating. A platinum anode is used. If a large area is immersed, the deposit is reddish in color; if the anode is partly withdrawn, the tendency is toward a pale deposit.

This bath is best made up new as required. Enriching it by addition of gold salt and potassium cyanide is not recommended.

The reason so short a period of plating is required is that gold has the property of giving an exceedingly thin and uniform coating. A very small thickness "covers."

Platinum-Plating.—Platinum-plating is not often done. The following is a formula for the solution for plating copper and its alloys:

Dissolve 17 parts platinic chloride in 500 parts of distilled water. Dissolve 100 parts ammonium phosphate in 500 parts of distilled water. Mix the solutions. A precipitate will be formed. Little by little a solution of 500 parts sodium phosphate in 1000 parts of water is added and the whole is brought to boiling, water lost by evaporation being constantly replaced until, the ammonia being boiled away, the solution becomes acid and loses the yellow color it possessed and becomes colorless.

This bath is used hot with a strong current, and its strength must be kept up by additions of the ammonium-platinum phosphate precipitate, obtained as above described.

Another formula is carried out by adding to a solution of platinum chloride a sufficient excess of potassium cyanide to form a clear solution of ammonium-platinum cyanide. A moderate current is required, or else a black powder will be deposited.

The anode in platinum-plating is always platinum.

Tin.—The following is a solution for the deposition of tin:

Sodium pyrophosphate	10 parts.
Water	1000 parts.

In this solution is dissolved 1 part of fused tin chloride (stannous chloride, tin protochloride). There is liable to be some difficulty in the solution. If pieces of the tin chloride fall to the bottom, they may become coated with a sort of crust which is difficultly soluble, and which retards the solution of the tin salt. One way is to put the tin salt into a perforated ladle, like a cullender, and keep the salt near the surface of the liquid, and agitate it until it dissolves.

The anode is of tin. The strength of the bath is maintained by adding, by means of the perforated ladle, equal parts of sodium pyrophosphate and tin chloride.

Another solution is made thus: Metallic tin is dissolved in hydrochloric acid, and is precipitated by addition of caustic potash solution. The precipitate is mixed with a solution of potassium cyanide and caustic potash until it dissolves.

Steeling.—A coating of iron is sometimes deposited on copper electrotypes of engravings in order to harden the surface. The iron thus deposited is so hard and durable that it is sometimes termed steel, although it is not steel at all, but pure iron. The bath may be thus prepared:

A solution of 1 part sal-ammoniac (ammonium chloride) in 5 parts of water is made. In it are suspended two plates of iron connected to the poles of a strong battery. After some hours the solution is ready, as some of the iron will be dissolved.

The electrotype which is to be steeled is put into the bath after thorough cleaning and washing with caustic potash solution. About 4 volts electromotive force are prescribed. After the steeling the plates are washed in cold water and rubbed with benzine. To preserve them from rusting they are covered with a film of beeswax.

Size of Conductors.—The conductors leading from the source of current to the bath should be as thick as convenient. All resistance of battery, generator, and conductors absorbs energy, which is wasted. The slight additional expense of large conductors is compensated for by the economy of power.

Current Intensity.—The quality of the deposit is greatly modified by the intensity of current per unit area of surface plated. Thus in a copper-plating bath too strong a current will give a

brown deposit almost powdery in quality. To remedy any such tendency when it is observed, the current strength must be diminished. This is easily done by raising the anode so as to decrease its immersed surface. Another way is to move the anode and objects plated away from each other in the bath.

If the current is too weak, the anode can be dipped deeper, or an extra one added, or the distance spoken of above can be decreased. The latter is only advisable when a rather flat surface is being plated, because an irregular piece near the anode will have a thicker deposit formed on its protuberant parts than on its retreating parts. The difference in distance between projections and recesses and the flat anode will vary less proportionately for large than for small distances between anode and object.

Too acid a bath gives less resistance, and tends to the development of too strong a current. Too little acid has the reverse effect. Copper deposited with too weak a current is crystalline and brittle.

A general rule is to have the surface of the anodes equal to that of the objects to be plated.

All such rules are only general. Thus, the question of excess of acid only applies to the limited number of baths in which free acid is present. Most baths are of alkaline reaction.

The Relative Position of Anode and Surface to be Plated has its effect on the result. They should be as nearly parallel as possible on general considerations. But there is a tendency for the lower parts of the objects to receive the thickest coating, as the solution tends in use to become more dense at the bottom of the bath. This tendency is counteracted by changing the position of the pieces, by moving them constantly, which is often done by power, and by agitating or stirring the solution in the bath.

When an object is quickly plated, these precautions are unnecessary. But when objects remain a long time in the bath, streaks are liable to appear on their lower area if they are not moved, or if the liquid is not stirred about.

The tendency of metal to be deposited most thickly on parts nearest to the anode leads to the following rule: When a piece in high relief is to be plated, the anode should be as far removed as is possible from the object. The anode can be increased in area

to compensate for the greater distance. Especially is this maintenance of distance important when the solution is of such nature as to attack the object to be plated. In such a case it may attack the object in its deep parts while metal is being deposited on its high places. A long distance as above is supposed to give a better quality of deposit as regards flexibility.

Sometimes for very high relief auxiliary anodes carried on supporting wires into the deeper parts of the relief may be used to secure the deposition of metal there.

Temperature of Baths.—The temperature of the baths has an important effect. For some baths heat is prescribed; for others, no heat is required, but they are to be used at the ordinary temperatures. Sometimes it is necessary to prevent the formation of insoluble deposits on the anode. These deposits may become so thick as to prevent the passage of any current.

The best way of heating the bath is to place the vessel in another larger one containing water. The water in the outer vessel is heated, so that the whole arrangement constitutes a water-bath. Or the bath may be placed on an iron tray filled with sand, which is heated. This constitutes a sand-bath. The sand enables the vessel constituting the bath to be more evenly heated than if it rested on an iron plate in more or less imperfect contact with it.

Material of Vessels.—For dipping baths for sulphuric acid a lead-lined tank may be used. For alkaline dipping sheet-iron or cast-iron vessels are excellent. For nitric or hydrochloric acid earthenware or gutta-percha vessels are best. Glass, enameled earthenware, varnished wood, or gutta-percha-lined wood are good materials for the plating baths.

Metal Molds.—Sometimes for reproducing articles molds are required. These give the reverse of the article. By depositing by the electric current a thick coating of metal on them, the mold is produced in reverse, which is the true reproduction of the original article. Molds are sometimes made of fusible metal. The following is an alloy suitable for the purpose:

Bismuth	28 parts
Tin	10 parts
Lead	19 parts

This alloy melts a little below the boiling point of water.

One way of using it for the reproduction of metals or coins is to melt it and pour some into a slight depression in a slab of marble. It will lie there in a flattened globule and will stay liquid for some time. The medal or coin to be reproduced is chilled and dried and is dropped flat upon the globule from a height of two or three inches. After the metal has solidified, the medal is separated by light jarring. An exceedingly delicate mold is thus produced, on which the plating is executed. Only a slight hollow in the marble is required to retain the melted metal.

Another alloy is the following:

Bismuth	250 parts
Tin	125 parts
Lead	160 parts
Antimony	30 parts

This alloy is used in a pasty condition, to which it is brought by proper degree of heating. It is then applied to the object. After cooling, a light yet decided blow will separate the two. The mold is then ready for its deposit.

Wax and Stearine Molds.—These are more generally used than metal molds.

Simple white wax or stearine may be melted and poured over the surface of the object, which latter has been previously oiled with a little olive oil. The wax must be allowed to cool several hours before any attempt is made to detach it from the original. Another way of using wax is to soften it by heat and to press the object into it. Other formulas are given, such as the following:

Spermaceti	225 parts
Beeswax	50 parts
Mutton tallow	50 parts

Plumbago may be mixed with these compositions with benefit. White lead in dry powder gives still better results.

The wax mixtures serve especially for the reproduction of flat objects, such as medals, coins, or for electrotyping.

Plaster Molds.—The object is covered with a thin coating of olive oil. Plaster of Paris mixed to a cream with water is painted on with a brush, and after perfect contact of plaster and object has been thus assured, the rest of the plaster is poured on. It may be held in place by a band of paper.

Elastic Molds.—For difficult pieces the plaster mold can sometimes be applied in sections, which are then put together after removal. This is not always an easy thing to do. Elastic molds are often used for such cases. These are made by mixing a strong solution of glue with molasses, about four parts of glue solution to one of molasses. By heating together a perfect mixture is obtained. This softens when heated, and on cooling becomes elastic, like a very stiff jelly. It is melted and poured over the object to be molded. A box may be used to hold the object and to prevent the composition from running off. Sometimes threads are led along the surface of the object, secured by glue, if necessary with long ends. They are drawn away through the composition when it has set, and divide it into sections.

This composition can be used on undercut and complicated objects. It springs out of shape on being drawn off, and springs back at once.

Gutta-Percha Molds.—Gutta-percha softens in hot water, can be pressed upon an object so as to give the most delicate outlines, and is indefinitely durable. Gelatine or glue compositions such as just described may give finer results, but do not form durable molds. Alcohol, acid, and alkaline solutions are without effect on gutta-percha. It is worked by being softened in hot water and pressed upon the object to be copied. When the object is of such a shape that the gutta-percha will not leave it, application of hot water will soften it enough to permit it to be removed, and as it cools it will retain the form given it by the object.

In using any of these materials, personal experience counts for a great deal.

Preparing Molds.—The molds of non-conducting materials just described have to be given a conducting surface. Such are glue mixture, plaster, or gutta-percha molds. Plumbago is generally used for giving this quality to them. The mold is moistened a little, by steam if of plaster, and the plumbago is applied by a soft brush. It is rubbed on until the surface is bright and metallic in appearance, and of uniform luster.

Copper powder is often mixed with the plumbago. It can be made by putting lumps of pure zinc into boiling and saturated solution of copper sulphate. The zinc is soon covered with the

copper precipitated. The lumps of zinc may be removed and the copper brushed off, washed, and dried. This powder can be used alone.

Sometimes fine iron powder is dusted over the surface after plumbago has been applied. On dipping into a solution of copper sulphate, metallic copper is precipitated by the iron, and helps to give a good surface for plating.

It is to be noted that deposition of metal spreads on all sides. If it begins energetically, in one spot, it spreads as well as builds up, and this action tends to produce even results.

Varnish.—Red sealing wax dissolved in alcohol is an excellent varnish for coating parts of objects on which no deposit is desired. Thus the sides and backs of the molds of fusible metal must be varnished to prevent deposition where it is not desired, and where it would prevent removal of the metal deposited.

Oiling.—For reproductions on metal molds, the surface must be slightly oiled to prevent adherence. Too thick a coating of oil will prevent the deposition of any metal, and makes the process inoperative.

Placing Molds in the Bath.—The general system is to place the molds vertically as near as may be and opposite to the anode. Sometimes the mold is placed horizontally below the anode. One objection to this arrangement is that if any dirt or scale is detached from the anode, it will fall upon the object and impair the result.

If metal molds are used, all connections of the anode should be completed before the mold is introduced. If not, there is danger that the mold may be attacked by the solution and oxidized. If the mold, connected to the zinc plate of the battery or equivalent wire of the plating dynamo, is introduced after the anode is in place, its introduction into the bath will be the last thing to complete the circuit, and it will be at once covered with a thin coating of metal. This is enough to prevent the mold from being attacked.

Plating on Molds.—In using non-conducting molds, it is well to begin with a current of low intensity. The deposit begins near the points of attachment of the conductor, and spreads laterally as already described. If hydrogen is disengaged, the coating will

be brittle, and to prevent this generation of hydrogen the current is started at low intensity. A wire may be used as electrode until the mold is pretty well covered with the deposit.

If air bubbles are seen in the interstices of the mold, they can be removed with a camel's hair pencil or other soft brush.

Backing Up Deposits.—A thin deposit will suffice in reproducing hollow objects, if it is strengthened by fusible brass or spelter such as is used for brazing. This can be put into the interior of the reproduction in small pieces with some borax. The blowpipe is then used to heat the whole to redness. The spelter runs, and is made to spread all over the surface by inclining the mold from side to side, so that it attaches itself to all the interior surface. The copper although thin resists the heat much longer than the spelter. It must be remembered that there is some danger of the spelter attacking and alloying with the copper and thus destroying the reproduction. Too long applied and too high heat will do this, and it will occur the more easily as the copper is thinner. If the copper is about one-tenth of an inch in thickness, there will be little danger of such an accident.

Plating on Glass.—A good deal of this work has been done recently, bottles especially having silver deposited upon them in various open-work designs and engraved as desired. Several methods have been used. Originally a varnish or lacquer was painted over the entire surface of the vessel on which the metal was to be deposited. When almost dry, plumbago was dusted over it, and it was polished with a soft brush. It was then wired, connected to the tank wire, placed in the tank, and left there for about eighteen hours' operation of the electro-plating current, or until a sufficient thickness of metal was obtained. The snow-white deposit of silver was polished. The designer then took it in hand, and painted a design with wax on the surface. The article was then immersed in an acid bath, and the silver not covered with wax was dissolved. Diluted nitric acid would answer for this operation. The engraver finishes the process by putting in any lines desired.

The plumbago with the lacquer formed a black background, which was undesirable. A more recent process has been substituted for the one described. Nitrate of silver solution mixed

with dextrose solution is poured over the article. Silver is deposited by reduction. Any of the methods of silvering used on astronomical reflectors, or so frequently used now on mirrors, can be employed. In this way an exceedingly thin coating of metallic silver is deposited all over the surface of the article. The electroplating is done upon this, and the processes detailed for the plumbago system are applied.

Finally, a metallic oxide has been applied with some varnish-like agent following the design. On baking the oxide is reduced, giving a metallic coating for the electroplating.

Practical Processes.—It must be kept in mind that in these as in other electroplating processes a description is not sufficient to enable operations to be successfully performed. Every electroplater has methods of carrying out processes which he has acquired by practice, and in many instances these methods are kept secret. A piece of plating may present an excellent appearance, yet on use the metal may scale off. A considerable interval of time may be required to show defects. It is therefore important when a good and satisfactory process is evolved to stick to it, and not to be too anxious to try something new.

CHAPTER XXXVIII.

TELEPHONY.

Sound.—Sound is due to vibrations of matter, generally or always vibrations of masses of matter. Thus a piano produces sound by the vibrations of its strings. A pair of cymbals dashed together vibrate, and produce sound. A plate of iron acted on by electro-magnetic pulses of attraction vibrates, and produces sound. The latter is the telephone receiver.

Pitch.—Sounds vary in pitch. Some are high and some low. The sounds of high pitch are produced by relatively high-frequency vibrations, sounds of low pitch by low-frequency vibrations. The lowest note in a church organ may be due to 16 vibrations and the highest to over 1000 vibrations per second.

Fundamental Note.—Every piece of metal or other solid has a note which is produced if the whole piece vibrates as a whole, and is called the fundamental note. If two pieces are of equal thickness and of the same material, the larger one will have the lower natural or fundamental note. This follows out the law of strings; the longer string in a piano has the lower note.

Overtones.—When a string in a piano is struck by the hammer, a number of notes are produced. The note due to the motion of the whole string in one arc of vibration back and forth is produced, and is called the fundamental note, due to what we may call n vibrations. Besides this the string produces notes of $2n$, $3n$, and other multiples of the fundamental note. The sound due to $2n$ vibrations is one octave higher, that due to $4n$ vibrations is two octaves higher, and many notes of intermediate value are produced every time a piano string vibrates. These high notes are called "overtones."

Sounding Plate.—The bottom of an oil can pushed in and allowed to spring out produces a sound due to its motion as a whole. In some sense it is a fundamental; at least it represents

the mechanical action of a half-vibration in each of its motions. If by some process a plate of metal can be made to vibrate as a whole, it would produce its fundamental note. Its motions would resemble those of the bottom of a spring-bottom oil can. Then if in addition the plate could be made to vibrate back and forth in a quarter of its area, as if divided by two lines at right angles to each other, one quarter springing up while the adjacent one sprang down, an overtone would be produced. If in addition to this the total surface vibrated in areas of one-eighth a still higher overtone would be produced.

The Human Voice when it produces musical sounds is very rich in overtones. When it speaks, a very complicated vibration of various fundamentals irregularly succeeding each other, and complicated by all sorts of higher-pitch vibrations in addition to what may be called the fundamentals, is produced. It is not exactly a case of overtone production, but of simultaneous vibrations of a number of pitches produced by the vibrations of the vocal organs.

Principle of Telephone Receiver.—In the telephone a plate of iron is acted on by impulses of attraction and release from attraction. These impulses vary in periodicity and intensity exactly as do the vibrations in the human voice. The impulses force the plate into vibrations identical in frequency and relative strength with those in the human voice. The plate in producing these vibrations does not vibrate as a whole, but is forced to divide itself into areas of vibration. The natural vibration period is not the controlling factor. The plate has to correspond to the pulses of current going over the line and through the coil of the telephone.

The pulses of current act upon the iron plate through the intermediation of an electro-magnet. The receiving instrument contains an electro-magnet connected to the transmission line. In front of the pole of this magnet a plate of iron is held very near to the pole. The pole faces its center. The changes in current passing through the coil are reflected in the attraction it exerts on the magnet. The variations in attraction, which may be many hundred in a second, force the plate into corresponding vibrations. The plate vibrates in subdivisions of its area, which sub-

divisions vary with great rapidity in number, areas, and shapes. A low note may make the plate vibrate in three or four areas, while simultaneous higher notes divide it into a quantity of smaller areas which vibrate without interfering with the large areas or with each other.

Such is the vibration of the telephone plate. It is easier to think of when we picture the complicated vibrations of a string producing a fundamental tone and a lot of overtones. But the telephone plate only gives its natural or fundamental note by chance coincidence. The magnetic attraction forces it into vibration often quite unnatural to it, and such as cannot be referred to its natural periodicity of vibration.

The Telephone Transmitter.—The above describes the theory of the telephonic receiver. It is connected by a wire with a distant instrument, which is spoken into and is called the transmitter. The original transmitter was an instrument which was a duplicate of the receiver. Two telephone receivers connected in an electric circuit can be used as a complete telephone system. The same instrument can act alternately as transmitter and receiver.

As transmitter, the above type performs the functions of a dynamo. The voice makes the plate vibrate in the same forced manner as described for the receiver. The movements of the plate, which acts as an armature of the magnet, induce currents of high frequency of impulse in the circuit, and the distant telephone reproduces them in its plate armature as described.

The intensity of the vibrations of the plate of the receiver is very much less than that of the transmitter. In the old-time telephones the speaker shouted into the instrument in order to make himself heard at the other end of the wire.

Invention of the Microphone.—Soon after the telephone was invented about 1876, the microphone was invented, and the great defect of the telephone was overcome. Shouting into the transmitter ceased to be a requisite. The microphone varies the resistance of the telephone circuit. A current is kept passing through it as long as it is in use. As the resistance of the circuit changes, the intensity of the current also changes. These changes act upon the plate of the receiver and make it produce sound.

The changes in resistance are produced by the sound waves produced by the voice acting on the microphone. The distant receiver reproduces the sound of the voice.

Hughes Microphone.—This is the original microphone, which has been modified indefinitely in the many telephone receivers which have appeared from time to time. Referring to the cut, Fig. 508, C is a board on which are screwed two blocks BB of hard carbon. Holes in the blocks receive the ends of a little rod of carbon A, which rests in its position quite loosely. The apparatus is placed in circuit with a battery as indicated, and with a telephone receiver. The least agitation to which the carbon rod is subjected causes the resistance of the microphone to vary. The variation in resistance causes the current to vary, and a sound is produced in the receiver. A fly walking on the instrument will produce a sound with every footfall. If talked against, the sound of the voice will be reproduced in the receiver more or less perfectly.

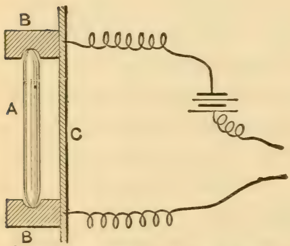


FIG. 508.—HUGHES'S MICROPHONE.

The Blake Transmitter.—For many years the Blake transmitter was the classic telephone receiver. In it a highly-finished block or button of hard carbon and a bit of platinum are held in contact with each other. One is pressed against a metallic diaphragm, the other is attached to an arm capable of moving back and forth. The primary circuit of an induction coil includes these two buttons, and the primary current, whenever the transmitter is in use, passes through the buttons from one to another, and therefore depends on their contact for its completion. When the mouth is placed close to the diaphragm and words are spoken, the vibrations of the diaphragm change the degree of pressure existing between the buttons, these changes exactly corresponding in form with the form of the sound waves. This variation of pressure causes changes in resistance, and therefore by Ohm's law in current also, corresponding in form with the sound waves. These changes of current acting on the distant receiver

cause its magnet coils to vary in excitation also in form corresponding to the original sound waves. This throws the diaphragm of the receiver, which is of iron and is the armature of the magnet, into vibrations exactly similar in form to those of the transmitter diaphragm, so that speech is reproduced.

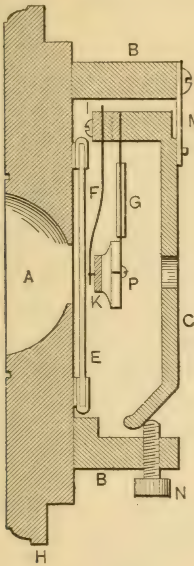


FIG. 508*a*.—THE BLAKE TRANSMITTER.

The Blake transmitter depends on pressure changes. Whether these affect resistance by direct variations in pressure or by changes in the area of contact due to pressure is not certain. It is probable that both actions have a part in the phenomenon.

The cut, Fig. 508*a*, shows the Blake transmitter. A is the opening to be spoken into, closed by a plate of iron or other diaphragm E. At the end of spring F is a bit of platinum, which presses against the diaphragm. K is the carbon button carried by a brass block P at the end of a spring G. B B are pillars, to the upper one of which a heavy counter weight C is attached by a spring. The lower pillar carries an adjusting screw N. The pressure between the platinum and carbon button is thus regulated, and the freedom given by the spring M, which carries the contact button and platinum contact piece, adds to the sensitiveness. The current passes through the contact by the springs F and G.

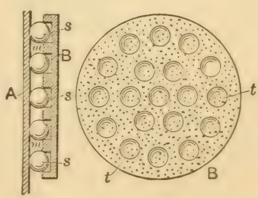


FIG. 509.—THE CLAMOND TRANSMITTER.

Loose Carbon Transmitters.—A variation in the Blake transmitter appears in instruments with quite loose carbon contacts. Thus, two disks of carbon, each with a number of depressions in them, may be

supported face to face, one attached to a diaphragm. The disks do not touch. In each pair of depressions, which face each other as the disks are placed, is a little carbon sphere. These are thrown into motion by the voice, and act exactly like the original Hughes microphone. Sometimes little carbon cylinders are used. The cut, Fig. 509, shows the Clamond transmitter.

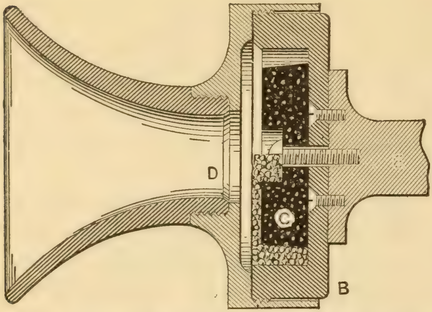


FIG. 510.—THE WESTERN UNION TRANSMITTER.

Hunning Transmitter.—The more modern type of receiver which has met with most favor in this country, is of the so-called Hunning type. This inventor substituted for the varying contact of a few pieces of accurately-shaped carbon, the varying contact of a quantity of granular carbon or carbon dust. It is on this basis that the modern transmitter is constructed.

In the cut, Fig. 510, is shown an exceedingly simple embodiment of this idea. To the right of D is a diaphragm, back of which is a second parallel plate B; the space between them is half filled with carbon dust C. The rest explains itself. This transmitter is of importance as involving the use of granulated carbon instead of regularly-shaped pieces.

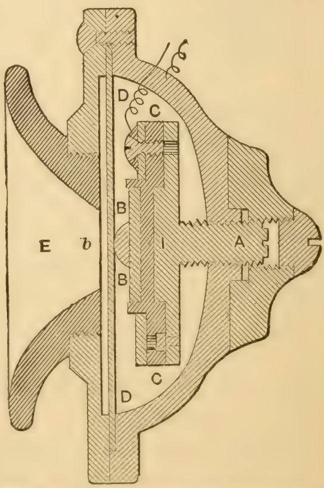


FIG. 511.—EDISON'S TELEPHONE.

Edison's Telephone.—This is shown in Fig. 511. E is the mouthpiece and D the metal dia-

phragm. I is a carbon disk with adjusting screw V. A platinum plate B B with an ivory button *b* is attached to the carbon disk. The ivory button is pressed against the diaphragm. C C is an insulating ring. The connections bring the disk into the circuit, and the resistance is varied when the instrument is spoken into.

The Solid Back Transmitter.—This modern instrument contains essentially the following parts: Two small disks of polished carbon face each other. They are in a cylindrical case of diameter slightly larger than their own. Their faces are maintained near together, but not touching each other. One is attached to the diaphragm, which is in modern instruments often made of aluminium. The wires from the primary of the induction coil go, one to one disk and the other to the other. The space between the disks and any space left in the cylindrical case is filled with fine carbon dust.

The action is similar to what has been described. The pressure exerted on the carbon powder by the disks is changed by the vibrations of the diaphragm. The powder is also agitated. One or both of these actions produces the changes in resistance, to which the transmitting power of the circuit is due. Which action is the prevailing one, or what degree of efficiency is to be ascribed to each, is uncertain.

The Receiver.—Modern telephone receivers are of several types of construction. The straight hand telephone embodies the following points in its construction:

Within a hard-rubber cylindrical case is a compound permanent horseshoe or U-shaped magnet. A more powerful magnet is produced by clamping together several thin steel magnets than where the magnet is made of one piece of steel as thick as the combined thinner ones. A lamellar or compound magnet is therefore the best. This magnet has its limbs so close that it fits into the standard India-rubber case. At its end are pole pieces projecting in line with its limbs, and on these are placed coils or spools of fine insulated wire, wound like coils on a horseshoe magnet oppositely to each other.

At its forward end the cylindrical case carries an expansion, somewhat like the mouth of a trumpet, over whose front a hard-rubber cover with a central aperture is secured by a thread cut

in the rubber. It screws on like the cover of a box. When in position it holds a disk of iron across the mouth of the tube very close to the magnet poles. The disk closes the aperture in the cover.

It is essential that the distance from disk to magnet poles shall be invariable. If the magnet were secured by its distant end, changes of temperature would constantly cause this distance to vary as the metal of the magnet expanded and contracted. In the older receivers this defect was present. The magnet was secured by its distant end to the case; sometimes it was fastened at both ends. In the latter case changes of temperature were liable to produce damaging strains.

In the modern instrument the magnet is fastened by its forward end only. The four or five inches of steel extends back into the case, and is free to expand or contract without affecting the adjustment. The critical distance between pole faces and metallic disk is invariable.

The bobbins are wound with very fine wire. One of the early troubles with receivers was the breaking of this wire. In the modern instruments it is protected absolutely from all strain. Through the bottom of the handle, closed with a solid disk of India-rubber, pass two binding screws. Within the case these connect to two heavy pieces of insulated wire, which by being twisted together or other simple arrangement, are held fast, so that the upper ends cannot be moved by any manipulation of the binding screws. The upper ends are connected to the terminals of the windings of the bobbins. This secures the fine wire from all strain. The telephone receiver is secure from all possibility of a broken circuit.

The working parts of a modern telephone receiver are shown in Fig. 512. The two limbs of the magnet are seen held parallel to each other, with their upper ends connected by a block of cast iron. On their forward ends are the two bobbins. The plate of iron is held by a screw cover across the opening of the cup, within which the coils are seen. The screw cover forms the part of the case which is held against the ear of the person receiving the message.

The Telephone Induction Coil.—The telephone transmitter is

placed in the circuit which includes the primary circuit of an induction coil and the exciting battery. This circuit is of far lower resistance than that of the long telephone line and of the coil or coils on the transmitter would be. In this fact lies one great incentive to its use. The sound waves vary the resistance of the microphone or transmitter, for the modern transmitter is invariably a microphone. If the transmitter is in a circuit of low resistance, its variations in resistance will be larger proportions of the total resistance of the circuit than if the total resistance of the circuit were high. A variation of 1/100 ohm on a 5-ohm circuit would be a variation of 1/500 of the total

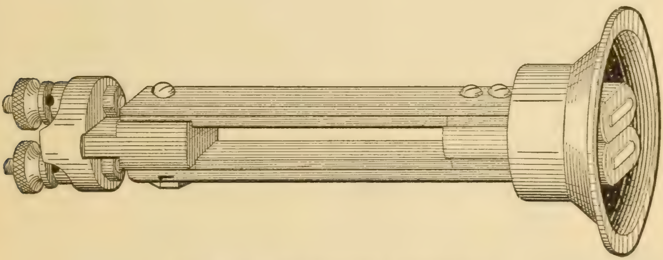


FIG. 512.—TELEPHONE RECEIVER.

resistance. By Ohm's law such a variation would cause the current to vary 1/500 in intensity. But if the circuit were of 300 ohms, the 1/100 ohm variation would only be 1/30,000 of the total resistance, and would only produce that variation in the current.

The use of an induction coil secures this feature. The primary of the coil and the battery for actuating it need only have a comparatively small resistance.

Acting as the primary of the induction coil upon the secondary, the variations in current due to the microphone action of the transmitter induce potential changes in the secondary. This impresses a much higher set of voltages upon its circuit, and a diminished current varying in intensity in proportion to the changes in the primary goes over the line. The receiver is wound for this current with many turns of wire, so that the action of the current on the magnetic field of the receiver is in-

creased or accentuated. The slight current multiplied by the large number of turns of wire in the receiver gives a tangible number of ampere turns.

The induction coil effects two things. It brings about a relatively high variation in the current changes, due to microphonic action, and it enables a much smaller wire to be used for transmission. There are other things involved, into which this book will not go, affecting the capacity of the line, the relative qualities for clear transmission of a small wire with small current or of a large wire with correspondingly large current, and other similar points.

In Fig. 513 B is a battery, T represents a transmitter, and P the

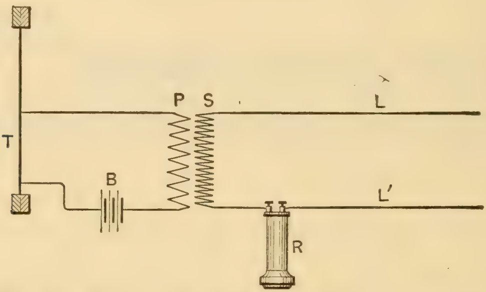


FIG. 513.—INDUCTION COIL IN TELEPHONE CIRCUIT.

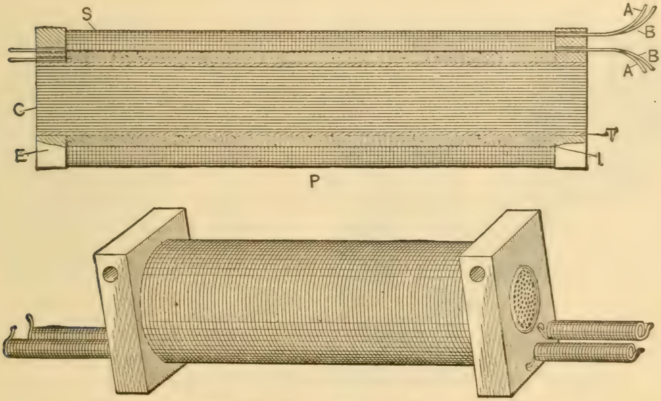
primary of an induction coil, whose secondary is indicated by S. The telephone receiver R is brought into circuit with the secondary of the induction coil by the line wire L L′. This illustrates the place of an induction coil in a telephone circuit.

The extension of the telephone is made much easier by the use of small wires. A lead-covered cable, not much over three inches in diameter at its bulkiest parts, such as joints, can accommodate wires enough for fifty or more metallic circuits. In the country almost invisible wires can be carried overhead through long spans at very slight expense. The induction coil makes these practicable in service.

Dimensions of Telephone Induction Coils.—The dimensions of

induction coils include the turns of wire in primary and secondary, the size and length of wires, and the consequent resistances. The iron core made of soft iron wires is not generally stated. The best dimensions are determined by trial rather than by calculation. Coils are tested over various lengths of line with transmitters of the class eventually to be used in the service. In general, it has been found that a coil good for one distance was good for another.

With the old Blake transmitter in this country an induction



FIGS. 514 AND 515.—TELEPHONE INDUCTION COIL.

coil of one-half ohm primary and 250 ohms secondary was used. An extreme case of a low-resistance coil has been used on long-distance lines in this country. This one had a primary coil resistance of 0.3 ohm and a secondary coil resistance of 14 ohms. The ratio or resistance in the first case was 1 to 500, in the second 1 to 46. The last-described coil had a very large core.

The following are the dimensions of a typical modern coil for ordinary work: Core about 5 inches long and 9/16 inch in diameter, composed of 500 strands of No. 24 American gauge soft Swedes iron wire. The core is contained in a thin tube of fiber with square wooden heads or flanges at the ends. The primary coil is wound on the tube. It is composed of No. 20 wire, and two

layers are wound in 200 turns. Paper is wound over it some layers deep, and the secondary is wound on this. It consists of two lines of No. 34 wire making 1,400 turns. The resistance of the primary coil is 0.38 ohm, of the secondary 75 ohms. This gives a resistance ratio of about 1 to 19 and of turns 1 to 7 only. Large wires are connected to the windings, and secured so as to prevent any strain coming on the windings.

Figs. 514 and 515 give a sectional view and side view of a modern coil with its primary coil and secondary coil wound on a core, consisting of a bundle of iron wire.

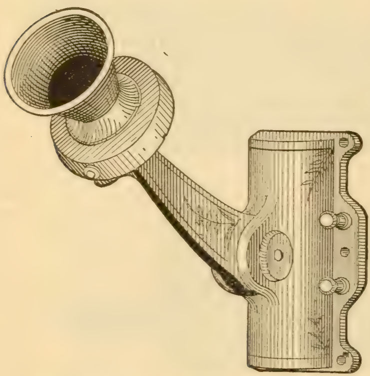


FIG. 516.—BRACKET TELEPHONE.

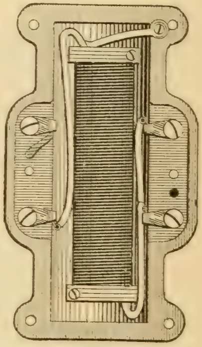


FIG. 517.—INDUCTION COIL IN BRACKET TELEPHONE.

Induction Coils in Bracket Telephones.—Coils are sometimes placed in the bases of swinging bracket telephones. Fig. 516 shows such a telephone, and Fig. 517 shows the section of the chamber at its base, within which the induction coil is placed.

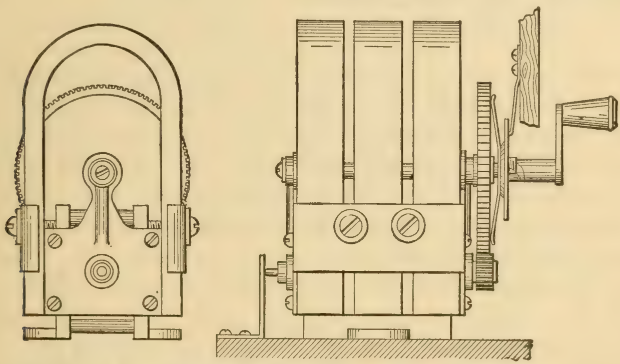
Effect of the Telephone Induction Coil.—The universal use of induction coils shows that they are valuable in telephony. The ratio of reduction of current is not so great as it would seem that it might be.

They exercise an effect on the current also. The microphone current is uniform in direction, but of varying intensity. By the induction coil this current is changed to an alternating one. The direction during the increase of microphone resistance is in

one direction, and during the decrease in the other. When the microphone is inactive, a steady current passes in the microphone circuit if the receiver is off its hook, while in the secondary induction coil circuit under this condition no current whatever passes.

In modern central battery practice they can no longer be considered to have much effect in reducing the size of line wire, owing to the absence of any battery at the customer's telephone apparatus.

The Telephone Magneto.—The bell magneto has already been spoken of in this book. Although not part of a telephone sys-



FIGS. 518 AND 519.—CALLING MAGNETO.

tem strictly speaking, so many have been and still are in use as calling apparatus that some description must be given of them here.

The magneto used for calling the central office consists of a field composed of several U-shaped permanent magnets, between whose poles a single-coil armature is rotated by turning a handle. On the shaft of the handle is a cogwheel which actuates a much smaller one on the shaft of the armature, so as to give it a sufficiently high speed of rotation. Two sprocket wheels and chain are sometimes used for the same purpose instead of gear wheels. Figs. 518 and 519 show a magneto generator, and Fig. 520 shows its armature core.

Some device is usually applied to cut the armature out of cir-

cuit when not in use. Sometimes the shaft of the large gear wheel is free to move in the direction of its length a short distance. In one position which it takes when at rest, it makes contact with the wire and short-circuits the armature. When the latter is to act, then the turning of the handle automatically shifts the shaft a short distance, and breaks the circuit, so that all the current passes through the armature. The shifting of the axle may be effected by the use of a cylindrical cam on which a projection on the shaft rides up. This cam may be formed on the hub of the large gear wheel, which wheel is so mounted that it cannot move along the line of the shaft, while the shaft can move back and forth through the aperture in its hub. In Fig. 521 this apparatus is illustrated. The large gear wheel C carries the cam on which the pin P rides up, shifting the shaft to the right and breaking the contact between its end and the spring O.

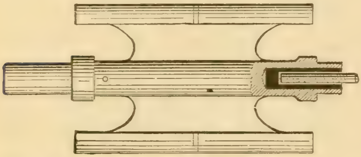


FIG. 520.—ARMATURE CORE OF MAGNETO BELL.

The magnets in this generator, made by the Western Telephone Construction Company, are made of magnet steel, in cross section ⅜ inch by ⅞ inch, and are bent into shape cold. The air gap, which is the distance from the armature surface to the surface of the magnet poles, may be as small as 1/100 inch. A cast-iron core turned so that it fits with this slight clearance between the poles is wound with insulated wire. The pole pieces of the magnet are attached to the ends of the magnets, and are bored out to form a chamber for the armature to revolve in.

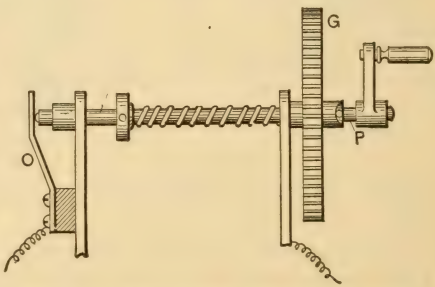


FIG. 521.—AUTOMATIC MAGNETO SWITCH.

Many different magnetos have been constructed, differing only in detail. The current produced is alternating and of the sine type approximately. The bells which are mounted on the face of the magneto case are rung by a hammer operated by an electro-magnet with polarized relay.

The armature is in improved constructions made of laminated type, built up of thin disks held upon a shaft. The pole pieces are sometimes laminated also.

The armature of the 10,000-ohm magneto is wound with No. 35 or 36 American wire gauge silk-covered wire. The classification of magnetos is based on the resistance of a line through which they can ring a bell. The figure such as 10,000 ohms above expresses line resistance, and has no direct reference to the dimensions of the magneto. The resistance of the armature of the above magneto may vary from 400 to 550 ohms. The magnets of the bells are wound with No. 31 American wire gauge wire to a resistance of 75 to 100 ohms. Silk-insulated wire is used for winding.

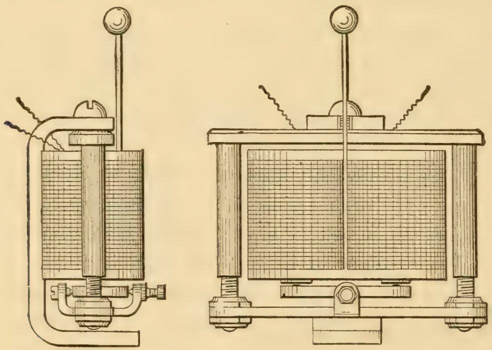
These dimensions apply to magnetos used on series work. But sometimes calling bells are connected across a circuit like lamps in parallel. Such arrangement is called in telephone practice bridging work. For this work a high inductance in the bell magnets is required to prevent the rapidly alternating speaking current from going through the coils. It must be shunted through the receiver in parallel with the bell magnet coils. The generator for bridging work should have a stronger field than that of the one just described, with a longer armature wound with No. 33 wire to about 350 ohms. The bell magnets are wound to as high a resistance as 1,000 ohms with No. 33 single silk-covered wire, or to 1,200 to 1,600 ohms with No. 38 wire. The thing principally wanted is not resistance, but inductance, so that they shall act as choke coils for the speaking current.

In central stations large magnetos or alternators are driven by power and kept constantly in action. Current for ringing is taken from them by the operatives as required.

Polarized Bell.—This is the bell which is rung by the magneto. It is shown in Figs. 522 and 523. The electro-magnet has an armature pivoted below it, and to the center of which the clapper

of the bells is attached. The armature is a bar of steel, and is magnetized so as to have a north pole at one end and a south pole at the other. When an alternating current from the magneto passes through the windings of the magnets, their strengths change with each alternation of current, so that the polarized armature swings first one way and then another, thus keeping the clapper in motion, so as to ring the bells placed within its range of motion.

Telephone Systems.—The general installation of a telephone system includes these elements: A microphone, termed the transmitter, is the apparatus spoken against. This is in a circuit through which a current flows when the transmitter is in



FIGS. 522 AND 523.—POLARIZED ARMATURE BELL.

use. On this circuit is a source of potential which maintains the current. Generally, this circuit includes the primary circuit of an induction coil. There is a secondary circuit of the induction coil, which is in circuit with the receiving instrument. The receiver, as it is called, is a modification and only a slight one of the Bell telephone of twenty-five years ago. To effect electrical connection between different customers, there is a central station. Wires from the customers' houses go to the central station, and by means of one or more switchboards communication between any two customers is brought about in a few seconds. Finally, calling apparatus is included. In the houses of customers this gives an audible signal, generally the ringing of a bell. In the central

office a shutter is dropped, making a click and exposing the number of the customer, or else in more modern practice an incandescent lamp at the customer's number on the switchboard is lighted when a call is made.

In many systems at the present day there is a battery in every customer's house. In more modern practice all the current is supplied from a storage battery at the central station. Protective devices to secure the system from lightning and damage from crosses with other wires are among details which form in modern practice essential parts of the system.

House Connections.—The house connections for a telephone

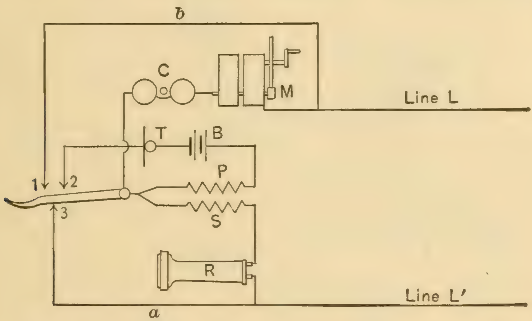


FIG. 524.—HOUSE TELEPHONE CONNECTION. HOOK-SWITCH DEPRESSED.

instrument with private battery have been variously carried out from time to time. A diagram of a typical system is given in the cuts, Figs. 524 and 524*a*. L L′ are the lines, M the magneto, C the call bell, T the transmitter, B the customer's battery, P and S the primary and secondary of the induction coil, R the receiver, and the hook-switch on which the transmitter is hung when it is out of use is seen on the left of the coil.

The first position shown is that in which the hook-switch is down. This is brought about in practice by hanging the receiver on the hook-switch. The illustrations show the circuit, including the receiver, induction coil, battery, and transmitter, and the connecting line *b*, all of which are thrown out of circuit when the hook-switch is depressed and connects with the stud 3.

An alternating current sent over the line from the central station goes through the magneto armature coil, then through the bell, ringing the latter, and by way of the hook-switch and stud 3 and connecting wire *a* back to the other line L′.

In this position, if the handle of the generator is turned, an alternating current will be sent over the line and will ring the bells at the central station or will operate any form of signal apparatus employed there.

The receiver is not shown on the hook, in order to make the diagram clearer. It is supposed to be hung upon the hook-switch.

On hearing the call the customer unhooks the receiver, and the hook-switch springs up. It opens the circuit at 3 and closes the

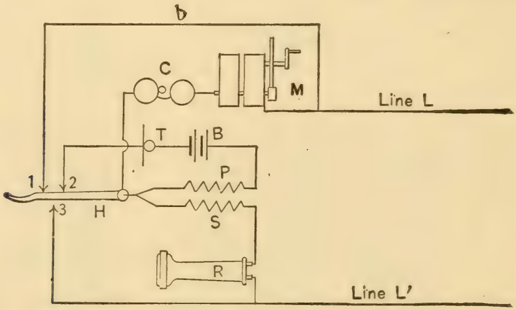


FIG. 524*a*.—HOUSE TELEPHONE CONNECTION. HOOK-SWITCH RAISED.

circuits at 1 and 2. The cut, Fig. 524*a*, shows the connections thus brought about. What before were inactive wires become active. The magneto and its bell are cut out of circuit.

Tracing the connections on this diagram, it will be seen that the receiver is now in circuit with the line L′, and through the secondary S of the induction coil with the line L. A message can be received by it. The transmitter is in circuit with the battery and primary of the induction coil. The circuit containing these three is closed through the contact 2 and the hook-switch. The hook-switch acts as a conductor for both primary and secondary currents from the induction coil, and as conductor for the talking current from the distant instrument. In the posi-

tion shown, the primary coil of the induction coil is on closed circuit, and a direct current goes through the transmitter.

When the transmitter is spoken into, the primary current varies as described, and the secondary current induced goes through the receiver to the line L L′, and through the hook-switch, connection 1, line *b*, to the other line L.

Series Telephone Circuit.—This is shown in Fig. 525. The

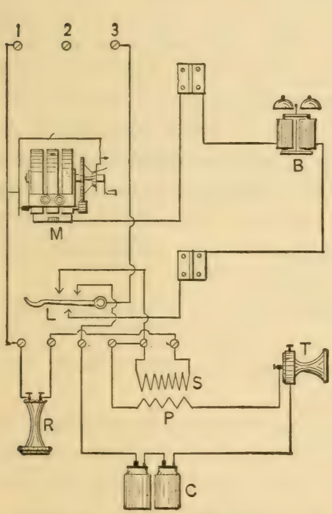


FIG. 525.—SERIES TELEPHONE CIRCUIT.

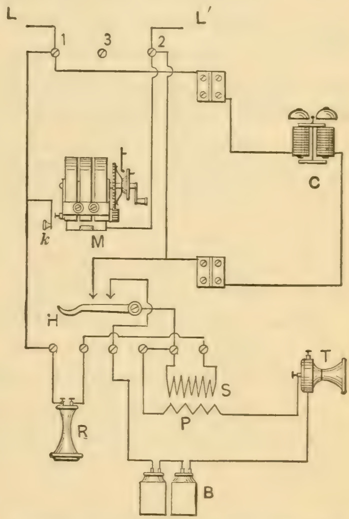


FIG. 526.—BRIDGED TELEPHONE CIRCUIT.

line wires connect at 1 and 3. When the hook-switch is depressed, the bell B is in circuit with the line and the magneto M is short-circuited. When the customer operates his generator this short circuit is automatically opened. When the hook-switch is depressed the receiver R is also cut out of the circuit. The connections are now adapted for calling up by the bell B only.

On unhooking the receiver R, the hook-switch L springs up, opens the bell circuit, and closes both the circuit of the transmitter T with the primary P of the induction coil in circuit with it and the circuit of the receiver R with the secondary S of the in-

duction coil in circuit with it. The connections are now ready to transmit and receive.

In this cut and in Fig. 526 central binding posts 2 are shown. These are for connecting to the ground for the lightning arresters.

Bridged Telephone Circuit.— Circuits of this description are characterized by the fact that the bell is connected across the lines permanently. A bridged circuit is given in Fig. 526. The bell C is permanently connected between the lines 1 and 2. Its magnets are wound of high resistance and have high inductance. Whether the hook-switch H is up or down, the bell circuit is in the same connection, being quite independent. But the resistance and reactance of its magnets make it an effectual barrier to telephonic currents; for them it is a choke coil. The magneto M is in a second bridged circuit, normally open, but closed when the handle is turned. These are parts of the calling circuit. The talking circuit with the receiver R in circuit with the secondary S of the induction coil is a third bridge circuit, open when the hook-switch is depressed.

When the telephone is taken off the hook, it rises and closes the talking circuit and also the local transmitting circuit. In the latter the primary P of the induction coil, the transmitter T, and battery B are included in series.

A switch is shown at *k* at the magneto. This is supposed to be operated by hand to close the magneto circuit when the central is to be rung up. An automatic closing device similar to that already described for the magneto is also used.

The Hook-Switch.—Considerable thought has been expended on the best construction of the hook-switch. Platinum connecting points or studs are the best, and it is an object to have a little sliding action as they open and close with the rise and descent of the switch. This tends to keep the contacts in good condition and free from dust. The contact action is only due to gravity when the receiver is hung up, and to a spring when the receiver is removed and the hook-switch springs up. If the contacts do slide, they should slide only on a conducting surface, not on an insulating surface and then on a conducting one. Sliding contacts bring about cutting as one of their objectionable features.

If platinum contacts are used, sliding contacts are not neces-

sary; for such metals as brass they are requisite. To prevent cutting, it is a good plan to make the two surfaces of dissimilar metals, just as in steam engine and heavy machine practice. The use of brass surfaces with German-silver springs, sliding as they make contact on the brass, is considered good practice. Sometimes the lever or hook-switch arm forms no part of the circuit, but it generally does. The journal or pivot screw should not be depended on as part of the circuit, but should be reinforced by a flexible wire twisted into a spiral spring, with its ends soldered one to the base, and one to the switch arm. It is well to pass the ends of the wire through holes and solder it in them after burring or riveting its ends.

Common Battery Systems.—The most advanced system of telephone installation has no local batteries in the house sets of tele-

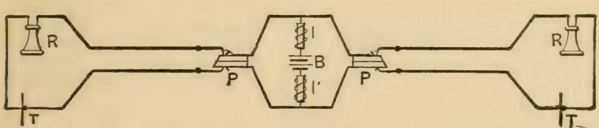


FIG. 527.—COMMON BATTERY METALLIC CIRCUIT SYSTEM.

phoning apparatus. In very many installations the local battery is still employed, and the circuits hitherto shown in this book have embodied it.

The simplest representation of a metallic-circuit common battery system is shown in Fig. 527. B is the battery at the central station. This is always a storage battery. At P are plug switches. The line drawn through the center of each switch indicates insulation of the two sides of the plug from one another. When the plugs are inserted, the two line transmitters T and receivers R and the battery are all thrown into circuit. It will be understood that the house connections are here omitted, the receiver and transmitter merely indicating them. They follow the general lines of those used with the local battery.

The system is shown in this cut as applied to several subscribers. The low resistance of the battery prevents any noticeable amount of current being deflected from one circuit into the other.

Sometimes choke coils are used between the central battery and the subscribers' lines. These coils permit the passage of direct current from the battery, which gives the basis for the transmitters to work on. The choke coils cut off all chance of intercommunication between independent circuits.

Stone's Common Battery System.—The diagram, Fig. 528, shows two circuits supplied from a single battery B. The coils used are of but slight resistance compared to that of the rest of the circuit, but are of considerable impedance. The battery maintains a direct current through any of the circuits it is plugged into or connected with. The transmitter when talked into causes this current to vary, and a speaking current is thus produced, restricted practically to its own circuit by the inductance of the coils. This inductance resists the passage of an alternating or

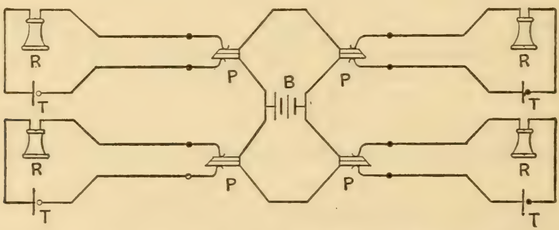


FIG. 528.—STONE'S COMMON BATTERY SYSTEM.

undulatory current, such as that of the speaking type produced by the microphonic action of the transmitter. This system is due to John S. Stone.

Dean's Common Battery System.—A most ingenious application of the choke coil enables both lines of a metallic circuit to be used in parallel for sending current to the transmitting circuit with a ground return. The diagram, Fig. 529, gives the general features of the system.

The central station battery B is grounded. It connects from its other terminal to the center of a choke coil I whose winding is connected across the two leads of the metallic circuit. At the subscriber's end of the circuit another choke coil, I, is connected across. From its center a connection is taken to a local closed circuit, including the primary of an induction coil and a trans-

mitter. A ground connection is taken from a point of this circuit opposite to the other connection and between transmitter and primary of the induction coil.

From the battery when all connections are made a direct current goes through the two branches of the choke coil I to both leads of the metallic circuit. It goes through both of these in parallel and through both parts of the choke coil I to its central connection. Thence it goes through both branches of the closed primary of the coil in the transmitter circuit to the ground. In this closed circuit the current divides. Part goes through the primary *p* of the induction coil, but without effect, as it is a constant current. Part goes through the transmitter T.

These variations in current through *p*, due to the voice acting

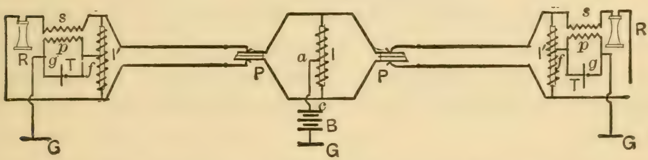


FIG. 529.—DEAN'S COMMON BATTERY SYSTEM.

on the transmitter, induce a speaking current in the metallic circuit, which includes the secondary *s* of the induction coil, and the receiver R at each station. The inductance of the choke coils prevents any of the talking current going through them, so that the circuit for talking purposes is a true metallic one.

By the use of choke coils on the same principles it has been proposed to have local storage batteries in the subscribers' sets, and to charge them from the central station. The use of choke coils enables the two lines of the metallic circuit to be used in parallel for the charging current with a ground return. The parallel circuit thus given is of one-half the normal resistance of the line. The current flowing in the same direction in both leads at the subscriber's station divides between the storage battery on one side and the transmitter with a special resistance coil on the other. The resistance coil and transmitter with their resistances in series shunt most of the current through the storage battery.

Party Lines.—The expense of a telephone distribution system is materially diminished by grouping private stations which are near to each other in groups of four or more, and serving them all with a single circuit from the central office. The first thing involved is the calling up of any one subscriber of the groups from the central station without calling up the others.

Polarized Bells for Party Lines.—In some systems polarized bells are used. The general principle of these may be given in a few words.

One type of polarized bell is one whose magnet armature is a permanent magnet, and which is attracted to the electro-magnet by current in one direction and repelled by that in another. If a current in the direction which attracts the armature is sent through the magnet coils, the armature will move toward the magnet poles and the striker will strike the bell. If the current ceases, it will be drawn back by the spring. An intermittent current in one direction will keep the striker in vibration, and the bell will ring continuously. If the current is in the other direction, it will repel the armature only and no ringing will be produced.

The bells in two of the subscribers' houses are connected to one lead of the circuit only, and are grounded from the other terminal. These bells are oppositely polarized. By sending a ringing current in one or the other direction, either bell can be rung as desired.

On the other lead of the main circuit two more bells, also oppositely polarized, are connected and grounded, each at a subscriber's house. By using this lead and sending ringing currents of opposite directions, either of these subscribers can be called up.

The four bells by this arrangement can be individually rung from the central station.

Eight bells can be individually rung by calling upon variation in current strength as well as polarity.

Four polarized bells wound to high resistance are connected exactly as described, on the four most distant stations. These can be rung by a light current one at a time as desired.

At the nearer stations four polarized bells are connected in series, two oppositely polarized on each lead. These are wound

to low resistance, and are not actuated by the slight current which rings the further bells. But if a strong enough current to ring one of them is sent, a relay situated beyond them is actuated and grounds the line at that point. The bell at the nearer station is then rung through the ground connection, which connection cuts out the bells beyond the house in question. In any case, only one of these would be rung, on account of its polarity and of the direction of the current.

Suppose that a line is fitted with four polarized bells as described on page 700 for four separate subscribers' stations. Using both lines in parallel, as if they were one, two oppositely polarized bells can be connected thereto and grounded. They can be operated exactly as the two bells on either lead of the line. The full metallic circuit can be utilized for two more bells. This gives eight subscribers on a single circuit.

In practice this system is operated by ordinary bells actuated from a local battery. The bell and battery are connected in a local circuit opened and closed by polarized and neutral relays, differently connected as regards their polarization, there being two relays for each station and bell.

The armatures of both relays at a house must be released from attraction and rest against their back-stops to cause their bell to ring. The operator by sending current in one or the other direction over one or the other of the leads, or over both in parallel, can ring any of the eight bells. One arrangement is to utilize six of the single-wire and through circuit connections for subscribers' signals, and to use the remaining two for locking the hook-switch, so that the central office cannot be called when the line is in use by another subscriber.

Harmonic Signal for Party Lines.—The armature of an electro-magnet can be mounted with a flat straight spring in place of a pivot. Such an armature if pulled to one side and released will swing back and forth and vibrate at a frequency depending on its weight, the length and the stiffness of the spring. If a series of impulses are imparted to it, coinciding in frequency with its own natural frequency, it will be caused to vibrate. If the impulses are irregular or have no correspondence with the periodicity of the armature movements, they will give it some

motion perhaps, but not with the same energy as if they harmonized with each other.

If through a magnet facing the armature impulses were sent, they would have little effect on the armature unless their frequency corresponded with that of the magnet. If their frequency was one-half or one-quarter or other integral fraction of that of the armature they would affect it, but would have most effect if of its exact frequency. Such series of impulses of current would start it into vibration. A contact point must be

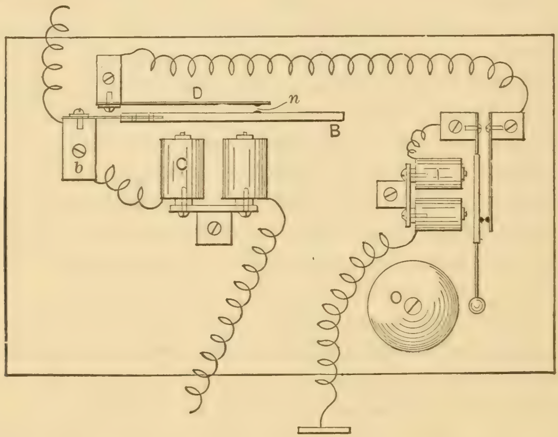


FIG. 530.—HARMONIC BELL SIGNAL.

provided with which the armature will make contact as it vibrates. By this contact a bell circuit is to be closed. For each closing the bell will ring. As long as the armature vibrates. the bell will ring in unison.

The cut, Fig. 530, shows the general idea of such a harmonic signal. The magnet C receives the current broken into impulses of definite number per second. When this number corresponds with the natural number of vibrations of the armature B, carried by the flat spring screwed on the top of the block *b*, the armature will vibrate, and only then.

If it vibrates, it will close the bell circuit at the point *n*, where

there are two contacts, one on B and one on D. When this contact is closed, the bell rings.

The armature B will not be thrown into vibration by a broken current whose impulses do not correspond with its own natural period of vibration. By having armatures of different rates of vibration at different subscribers' houses, any subscriber can be called by a broken current of frequency corresponding to that of his armature.

In some systems the vibrations are used to close a bell circuit as above, in some to open a shunt in parallel with the bell, and which when closed prevents it from ringing by taking the current. In some the bell-hammer and armature are one.

The harmonic system is very little used in American telephone practice.

A practical limitation exists to the number of subscribers that can be served by one wire, because the amount of service exacted by four to six subscribers is about all that one line can take care of. If harmonic calls were used, only four to six rates of current impulses would be needed at the central station.

Distributing Boards.—A central telephone station may have six thousand or more individual circuits entering it. Every one of these has to be taken to its place, where a number is assigned it on the main switchboard, which in all large offices is of the multiple type. The mass of wires back of the main switch is complicated, and if it had to have its connections changed and shifted about, endless confusion would result. To avoid the necessity for changing the wires at this point, a special arrangement called a distributing board is used. It provides two faces or boards, separated a little from each other. On one face are secured all the wires of the circuits which enter the building. These connections are supposed never to be disturbed under ordinary conditions.

A multiple switchboard has a number of identical panels. Each panel has plug sockets for all the circuits that enter the building, with perhaps one or two thousand others to provide for future extensions.

Circuits from the multiple switchboard equal in number to the sockets on one panel of the board run to the other side of the

distributing board. As the panels of the multiple switchboard all are connected, No. 1 to No. 1 and so on all the length of the board, it follows that every connection on the distributing board connects with every panel of the multiple switchboard.

It does more than this. Taking No. 1 connection from the distributing board, this wire connects with every No. 1 plug on the switchboard. There may be fifty or more panels, on each panel a single No. 1 plug and all connected to one circuit. This circuit goes to No. 1 connection on the distributing board. The same is done for every socket on each panel; a connection from all of each given number runs to a corresponding number on the distributing board.

These connections are normally never disturbed.

The space of some feet in depth intervening between the front and back of the distributing board is bridged across by wires, one for every active connection on the switchboard. These wire connections are subject to frequent change. If it is necessary to change a subscriber's number, the wire from his connection to the distributing board is connected to the other face of the board, to the connection leading to the desired sets of numbers on the multiple switchboard.

The shape the distributing board takes is a sort of open rectangular rack. Several feet intervene between the two faces, and within this space the connections are made. There is little that is distinctive about them. Each one has to have front and rear connections corresponding in number, and on the face next to the switchboard they must correspond in designation with the sockets on each panel of the multiple switchboard.

A wire circuit enters the building, and is connected to the rear of the distributing board. It may be decided to connect it to the set of sockets numbered 75 on the multiple switchboard. By short wire leads within the distributing board the connection from the incoming wire to the No. 75 connection on the other face of the distributing board is made. This one connection puts the subscriber whose wire circuit is thus disposed of in connection with every plug bearing the number 75 on the multiple switchboard, as well as with the calling plug for the operator.

Fig. 531 gives a cross section and view of the side of a distributing board. At C a cable from the street is supposed to enter. Its end is opened, and wires *w* are taken from the cable head H and carried to the near face of the board. Wires from the other face run to the plug connections S S on the switchboard C. Wires called bridle or jumper wires connect the front and rear connections of the distributing board with each other.

The board illustrated is the Hibbard board. The frame is open work built of iron pipe, forming a sort of trellis.

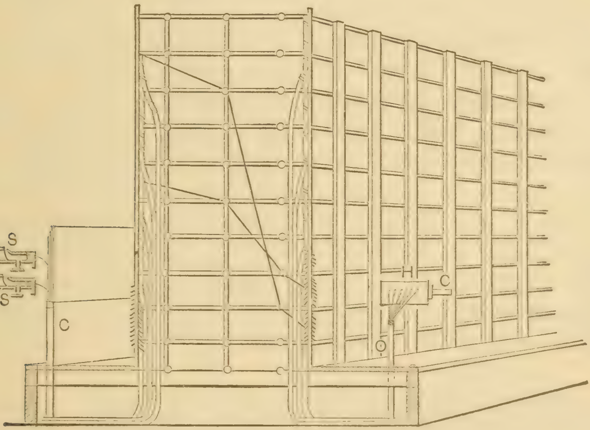


FIG. 531.—DISTRIBUTING BOARD.

It has been aptly said that the object of the distributing board is to concentrate the changes of connections into a definite locality. The short wire connections are of No. 20 to 22 wire tinned, rubber-covered, and twisted in pairs to give the elements for continuing the metallic circuit. Lightning arresters are often included in the connections The best and generally accepted practice is to solder all the jumper wire connections.

Repeating Coils.—The repeating coil used in telephone practice is an induction coil. Its core is made of a bundle of annealed iron wire. Its windings are generally of the same number of turns and of the same size of wire for both primary and second-

ary circuits or windings. It is used to cause the speaking current in one line to be transferred to another. It has four binding posts—a pair for each circuit.

Thus a ground telephone circuit may extend to a certain point in the district and there terminate. Its end may be connected to one terminal or binding post of the coil, whose other corresponding binding post is grounded by another wire connection. To the other pair of terminals are connected the ends of a metallic telephone circuit.

Any conversation on the grounded line will be transferred to the metallic circuit by induction, and the reverse action will also take place. Thus, a circuit may be part grounded and part metallic.

One principal use of this combination is to avoid interference from other lines, and not have the expense of a full metallic circuit system. Where there is no danger of interference a ground circuit is used, with one winding of the repeating coil in series at its outer end. For the part where interference is feared a metallic circuit is put in, with the other winding of coil in series. By another repeating coil a ground circuit may be brought into the circuit again if the area of disturbance and interference is passed. There are other uses of the repeating coil in central station practice.

The Multiple Switchboard is used in central telephone exchanges to effect the connection of one subscriber with another. If there were but one or two hundred subscribers in a district, the connections between them could be effected by a single board. On the board the terminals of all the subscribers could be placed and each one numbered. A flexible wire with proper end connections could connect any subscriber's terminal to any other.

If there were some thousand subscribers in a district, it would be impossible for a single operator to answer all the calls which would come in from them. Therefore, it would have to be determined what number of subscribers could be attended to by a single operator. Each operator would have a calling-up board or set of connections to a limited number of subscribers. These subscribers would be able to call up this operator and no other.

Calling-up connections for the entire number of subscribers

are arranged along the full length of the switchboard. The number that one operator can take care of are arranged within reach of the arm as the operator sits on a chair or high stool.

For each subscriber there is only a single calling-up connection. This portion of the switchboard is single, not multiple.

Each operator must without leaving the chair be able to connect any one of the limited number of calling-up connections, which may vary in different cases, to any one of the subscribers in the whole district, who may be several thousand. In front of each operator is a panel of the board, with a connection on it for every one of the subscribers, and all these connections within reach of the arm. Corresponding in width with the panel is the row of calling-up connections. If there are fifty operators, there are fifty panels. Every connection of a given number on one panel is repeated there fifty times along the series of panels. This multiplication of panels constitutes the multiple feature of the switchboard.

1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
6 7 8 9 10	6 7 8 9 10	6 7 8 9 10	6 7 8 9 10	6 7 8 9 10
11 12 13 14 15	11 12 13 14 15	11 12 13 14 15	11 12 13 14 15	11 12 13 14 15
16 17 18 19 20	16 17 18 19 20	16 17 18 19 20	16 17 18 19 20	16 17 18 19 20
21 22 23 24 25	21 22 23 24 25	21 22 23 24 25	21 22 23 24 25	21 22 23 24 25
1 2 3 4 5	6 7 8 9 10	11 12 13 14 15	16 17 18 19 20	21 22 23 24 25

The diagram shows the relation of panels to calling-up connections, and also indicates the multiple connections for identical numbers of the series of panels. Each panel is shown with twenty-five subscribers' connections, and five calling-up connections are shown for each panel. This is as if each operator was only called up by five subscribers, and as if there were only twenty-five subscribers in the district. In reality there might be several thousand connections on each panel, and fifty to two hundred calling-up connections for each panel. Each panel indicates one operator; as above shown, there would be five. The total number of subscribers divided by the number of panels gives the number of calling-up connections to one operator. The number of panels fixes the number of operators, and under each panel are the number of calling-up connections, each one for a

designated subscriber, which that particular operator must answer.

The number of calling-up connections which one operator can attend to depends on the number of subscribers. When there are a large number of subscribers connected to a central station, each one will call for more connections in a day than if there were only a few. If a subscriber has six thousand co-subscribers at a station, he will call up more times in a day than if he only had one thousand or five hundred. Therefore, as the number of subscribers in the district served by the central station is larger, the calling-up connections assigned to each operator must be fewer in number.

The number of operators required on a multiple switchboard does not increase in simple ratio. Doubling the number of subscribers exacts more than double the number of operators. The rate of increase approximates to the geometric ratio.

The above simple description merely gives the outlines of the theory of the multiple switchboard. As it comes in practice when there are several thousand subscribers to be included in every panel, and where the panels have to be consequently very numerous, the complication becomes enormous.

There are a number of modifications designed to bring about more efficient working.

Operation of Switchboard.—Calling-up connections of the subscribers on a multiple switchboard are operated by the subscriber. When the handle of his magneto is turned, or when the receiver is removed from the hook-switch as the case may be, a current is sent over the line. At the calling-up connection on the switchboard in the central station this current operates some kind of annunciator to indicate the number of his station to the operator.

The Mechanical Annunciator is a falling shutter or drop, seen in so many forms in ordinary house-bell annunciators, in hotel annunciators, and the like.

A little shutter hinged at the base is held up in a vertical position by a catch or hook which holds its upper edge. The hook is operated by an electro-magnet. When the magnet is excited by a current passing through it, it attracts an armature

to which the hook is attached. This raises the hook, and the shutter at once drops. On its inner surface is painted or otherwise marked the number of the subscriber's station to which its circuit is connected. The current sent over the circuit by the distant subscriber drops the shutter and discloses his number. The operator replaces the shutter by hand as soon as the magnet releases its armature, so that the retaining hook drops to its lowest position. The drop is now ready for another call.

Such annunciators are used in great number. An advance is made by having an electric system of replacing the shutter.

It is considered that automatic setting of the annunciators effects a saving of time and energy for the operator, who is often worked to the full extent of her power during the busy hours of the day. Where mechanical annunciators are used, the tendency is to use self-restoring drops.

Lamp Annunciator.—The most advanced practice on switchboards is to substitute incandescent lamps for mechanical drops. Eight- to twenty-volt lamps are used, one for each calling-up connection. A simple low-voltage lamp represents the maximum of simplicity and takes the place of the mechanism of the drop, inevitably more or less complicated. Lamps are cheaper than the modern self-restoring drops. They operate when current passes, and cease when it ceases, thus presenting the self-restoring feature of the most improved drops without complication of the latter. Lamp signals are rapidly coming into use on the larger and more important switchboards. At first very low voltage lamps were used. These proved quite unreliable; they were very sensitive to slight changes in voltage, were hard to make. and burnt out very easily. Ten- to twenty-volt lamps are now frequently used.

To produce the lighting current a storage battery at the central station is used. This gives an almost constant voltage. By having the lamps of reasonably high voltage, a drop or rise of a fraction of a volt has a much less effect on the duration of a lamp than when they are of only two to four volts potential. One-half of a volt on a two-volt lamp is twenty-five per cent of its voltage. On a twenty-volt lamp it is only two and a half per cent.

In one system the removal of the receiver from the hook-switch throws the lamp into circuit with the station storage battery. The lighting current goes through the whole line, and through the transmitter at the subscriber's station.

Several objections have been cited in reference to this system. The valid one is that if a cross occurs between lines, a very low resistance circuit may be produced, through which current will reach the lamp. The low resistance will operate to burn out the lamp. A very obvious way to dispose of this trouble is to put the lamp on a relay circuit. The calling current closes the relay, and the lamp is lighted from the storage

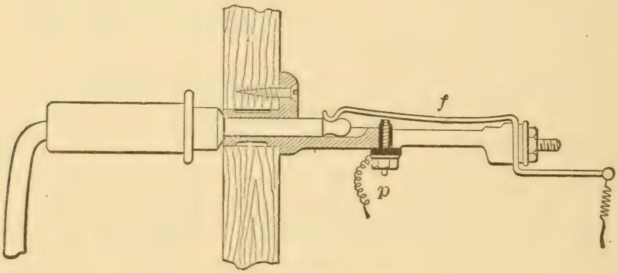


FIG. 532.—SPRING JACK.

battery through the unchanged resistance of the local circuit. Apparently more complicated than the straight circuit system, the relay system avoids the necessity of adjusting the resistances of long and short circuits so as to give each of the lamps the proper current.

Spring Jacks.—Connections to subscribers' lines on multiple switchboards are made by the agency of plugs thrust into spring jacks. Some boards have between one and two hundred thousand spring jacks. Fig. 532 illustrates the principle of construction of one kind. The spring jack is screwed to the back of the board, and a tube in its front projects through it. When the plug is withdrawn, the spring *f* rests on the contact screw *p*, and a closed circuit is made through the spring jack. When the plug is pushed into place, it pushes the spring up from the

contact screw, opening the circuit and connecting its own lead thereto.

The front of a telephone switchboard appears full of holes, regularly spaced, and along the middle level appears a straight row of such holes extending its whole length. These are the spring jacks. On a five-panel board each subscriber will have

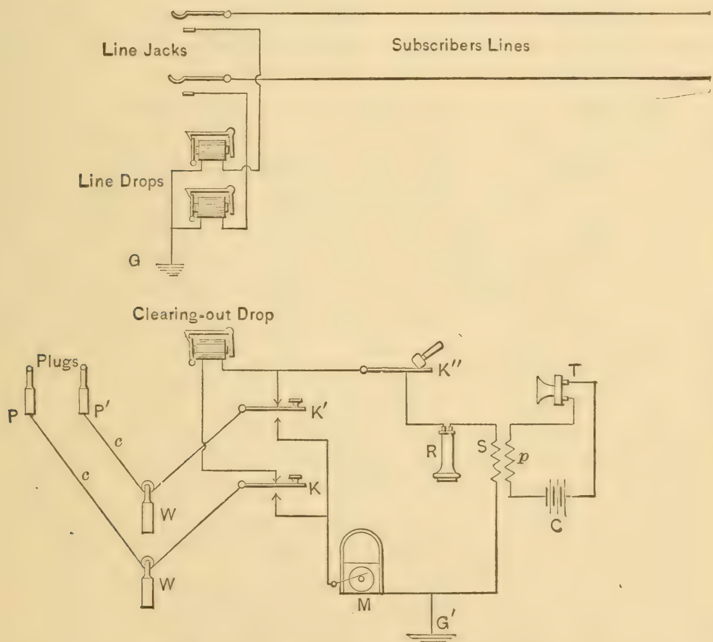


FIG. 533.—SWITCHBOARD CONNECTIONS.

six spring jacks; five are on the face of the board and one is in the horizontal row.

Various constructions of spring jacks are in use. They may act to give a simple metallic contact, or if the plug is in two divisions insulated from one another, a double connection may be made by plugging the hole. A flexible wire ("flexible cord") is connected to the plug.

Switchboard Connections.—The diagram, Fig. 533, illustrates the work of a switchboard. Two subscribers' lines are shown entering an exchange, each including in its circuit an annunciator drop. When the subscriber by magneto or otherwise sends a current over his line, his special annunciator drop falls and discloses his number. Spring jacks such as have just been illustrated are indicated, one for each line. It will be seen how in their closed position, which is when the plugs are not inserted, the spring jacks act to complete the circuit through the annunciators to the earth at G.

In the lower part of the diagram are shown the switchboard connections. R and T are the receiver and transmitter used by the operator; B is the local battery, which with the transmitter T is in circuit with the primary *p* of an induction coil. P P′ are plugs to go into the spring jacks at the top of the cut.

Assume that a subscriber desiring to use the telephone has by means of his magneto sent a current through his line. It drops the shutter of an annunciator, disclosing his number. The operator inserts the plug P′ into the subscriber's spring jack. Each spring jack, it will be understood, has its number, that of the subscriber to whom it belongs. When the plug is inserted in the socket with the same number as that shown when the shutter drops, the subscriber is cut off from the ground at G, and is connected in circuit with the operator's receiver R and secondary S of his induction coil to the ground at G′. Immediately on inserting the plug, the key K″, which has been hitherto open, is closed, completing the circuit described. The operator by the transmitter T asks the number desired, and the subscriber tells it. The operator receives it by the receiver R. The plug P is inserted into the spring jack of the subscriber who is to be called up, and the key K is depressed. By working the magneto M the bell of the second subscriber, the one who is to be called up, is rung. When the second subscriber has answered, his answer being received by the operator's receiver R, the keys K and K″ are opened, and the subscribers are in circuit with each other, and can speak together. The operator can listen by closing or depressing the switch K″.

When the subscribers are through they both probably ring

off, although it would be just as good if only one did so. This sends a current through the coil of the magnet of the annunciator, called the clearing-out drop. Its shutter drops, showing that the conversation is finished. The plugs are pulled out of the spring jacks, and the lines are again ready for work.

The proportion of plugs for a given number of subscribers is a matter for consideration. One pair of plugs for every ten subscribers is a proportion which in many cases is found advantageous.

Lamp Signal System.—A simple presentation of the lamp signal annunciator system is given in Fig. 534. The subscriber's apparatus is shown in the upper part of the cut at B, and the central office connections in the lower part of the cut at C. At C, *g* and *h* indicate choke coils, *l* the annunciator lamp, and *i* a battery; *g*, *h*, and *l* are all in one metallic circuit. There is one such circuit with numbered lamp for each subscriber.

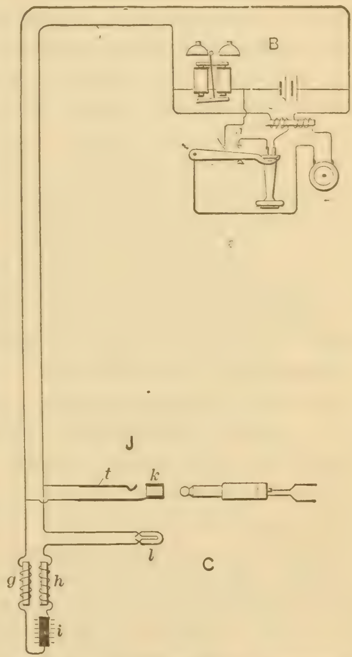


FIG. 534.—LAMP SIGNAL SWITCHBOARD CONNECTION.

When the receiver is on the hook-switch, the circuit including the annunciator lamp *l* is closed through the high resistance of about 1000 ohms of the calling bell *e*. This cuts down the current so that the lamp *l* shows no light. When the receiver is taken off the hook-switch, this springs up and closes a circuit as it does so by coming in contact with two terminals above it, as shown at C. This short-circuits the bell coils. In the short circuit is included the secondary of the subscribers' induction coil. But this short circuit may aggregate less than 50 ohms

resistance, and the lamp is lighted. This calls the central station operator, who effects the desired connection, when told it by the calling subscriber.

The local battery at the subscriber's house is a storage battery. When the hook-switch is released, this battery operates the transmitter. When the receiver is hung on the hook-switch, the secondary battery is in closed circuit with the coils of the calling bell magnet, and receives a slight charging current of about 1/50 ampere. This keeps it in good condition for use.

This description is of the simplest kind of lamp signaling system. There are many modifications, involving more complicated connections.

If the local battery becomes too weak, the subscriber's transmitter will work with current from the central station battery, and the local battery will act as a sort of equalizer.

In general practice, the calling lamp is on a relay circuit, and the relay closes its circuit when the receiver is taken off its switch, by short-circuiting somewhat as described above.

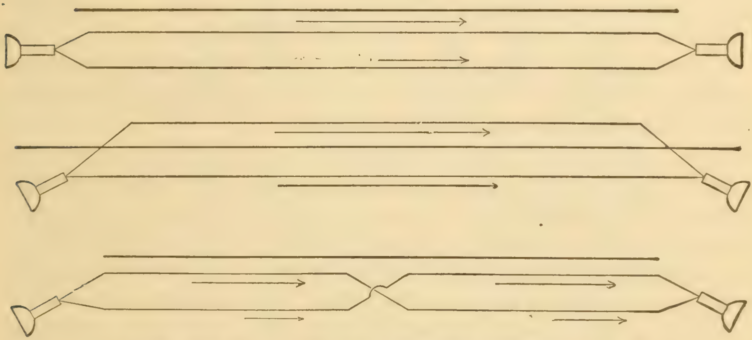
Conduction Interference.—Electric conductors such as line wires are sometimes subject to much trouble from induction and other electric disturbances. This is especially true of telephone lines. The telephone receiver is a wonderfully sensitive detector of any current change. It tells nothing if a constant current is passing through it, but reveals sudden changes in intensity of the current passing through it by producing a sound. Grounded circuits are peculiarly subject to disturbance. A grounded telephone circuit may be rendered quite useless by the presence in its vicinity of an electric trolley. The latter use the rails as their return circuit, and some of the current leaks into the ground and into grounded circuits in the vicinity. A grounded telephone line will sometimes sound in accord with the motions of the car motors. A part of the return current will go through the line, following the law of divided circuits.

Induction Interference.—The above is a disturbance by conduction. Sometimes induction from neighboring irregular currents will affect a line. Insulation is without effect on induction, so whether the wire is insulated or bare, it will suffer disturbance as far as telephonic uses are concerned. A neighboring

telegraph line will act on a telephone line, so that its signals will be heard in the receivers.

Such induction is usually treated as electro-magnetic. Experiments go to show that it is electrostatic. If a telephone receiver is placed in the center of a line, and one at each end, the end receivers will give a sound when a disturbing circuit acts on the line, while the central instrument will be mute. Even if the line is cut in the center, the two halves will give current changes which will make the end telephones sound.

The use of metallic circuits does away with much of this



FIGS. 535, 536 AND 537.—TELEPHONE LINE INDUCTION.

trouble. If the disturbing line lay parallel with and between the two leads of the metallic circuit and equidistant from both, it would affect both leads equally and in the same direction, so that the two effects would neutralize each other. But in practice the disturbing line never occupies just such a position. One or the other lead is nearer to the source of disturbance than the other, and a disturbance results, which may be very annoying, particularly in telephone service.

In Fig. 535 the heavy line indicates a circuit of varying current. The telephone circuit is seen parallel with it, with one side nearer to it than the other. The nearer side of the telephone circuit will have the stronger potential impressed on it, and the result is indicated by the relative length of the arrows.

The induced current will be due to the difference of the electromotive force on the two leads of the telephone circuit.

In Fig. 536 the effects of an inducing wire equally distant from both the telephone leads is shown. Equal electromotive force is impressed on both leads and in the same direction. Therefore no current is produced, and the telephones are unaffected.

In Fig. 537 transposition is illustrated. The wires are unequally affected because of their different distances from the source of disturbance. If the result is followed out on the diagram, it will be seen that the net result is the impressment of equal electromotive forces on both leads of the wire and in the same direction, so that they neutralize each other.

In induction the polarity of the electromotive force induced constantly changes. The arrows in these diagrams illustrate the condition at one instant of the induction.

When a number of lines are carried on one set of poles, the transpositions of the lines must not be the same for all. If the identical transposition were given to all, there would be mutual induction. This induction is avoided by transposing the leads of the different circuits at intervals or at points varying for each pair of leads. Thus, two pairs of lines may be transposed at intervals of one mile for each case. To overcome mutual induction the places of transposition may vary, so that there would always be one-half mile between them. Other pairs could be transposed every half mile, and could also be varied in their places of transposition.

Transposition on pole lines is effected by transposition insulators. These have two grooves. The wire is cut, and each end is turned about the insulator in its own groove. The same is done for the other wire of the circuit, and by short wires the rear end of one lead is connected to the forward end of the other, and the remaining ends are cross-connected in like manner.

Twisting the leads of a circuit is much used. This secures comparative immunity from induction. In cables containing a number of pairs of wires twisting is extensively applied, and has been found to prevent induction.

Induction troubles are felt most on telephone circuits. Ordinary telegraph, power, or lighting circuits are relatively or completely free from them. The cable construction companies endeavor to supply non-inductive cables, and have much success in their construction.

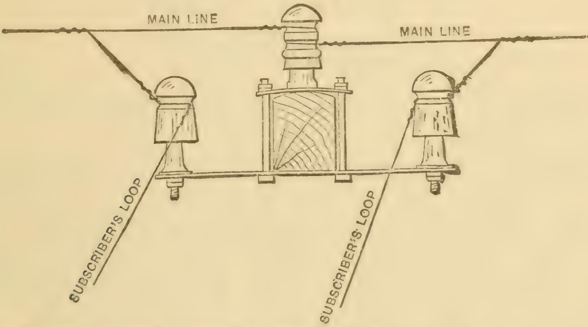


FIG. 537*a*.—POLE CONNECTIONS FOR SUBSCRIBER'S CIRCUIT.

Subscriber's Pole Connections.—The method of taking a subscriber's connection from a pole line is shown in Fig. 537*a*. A double-grooved insulator, such as referred to in the preceding paragraph, receives the ends of the line wire, which is cut at this point. From the ends a branch circuit is taken, as shown in the cut, two single-grooved insulators being provided, which take the strain off the main line insulator.

Improvements.—No branch of electrical engineering is more subject to development and improvement than telephony. The utmost that can be done in these few pages is to give the outlines of what is a very complicated subject, much of whose theory is largely unformulated. Automatic exchange systems dispensing in part or in whole with the central station operators are coming to the front, and if they ever reach full development, may exercise profound influence on the future of the business, by introducing a different ratio of expenses to number of subscribers.

CHAPTER XXXIX.

BELL WIRING.

Bell Wiring is a class of work in which bad insulation leads to endless trouble.

Size of Wire.—Cheapness often induces the use of undersized wire. A small current will ring a bell, and the lengths of wire in a house are so short that the question of resistance hardly needs to be considered. Undersized wire is objectionable because of its weakness. Wire stapled to joists under a floor, and led back of lath and plaster, seems out of all danger, but thin wire in house work will break and give much trouble. Circuits sometimes need changes; an extra bell, or more likely an extra push button, is to be put in. Thin wire is far less easy to connect, because it is liable to break and give the work of extra splicing to restore it. Wire in houses is sometimes cut by tacks or nails. Heavy wire has at least a better chance of escaping this accident than thin wire has.

Nos. 16 and 18 American wire gauge are standard sizes. When No. 20 or even finer wire is used, the standard of the work is greatly lowered. The wire should be double-coated and paraffined. This makes it slippery, which is a great advantage, because the coating is not so much injured by pulling around corners as a wire without paraffin in its coating would be. This is an incidental advantage. The first object of the paraffin is to improve the insulation and to exclude dampness.

In putting wires into a finished house, they have often to be led up or down between studding and back of the lath and plaster. The processes used are called "fishing." In executing this, the greatest care should be taken to avoid dragging the wire around a sharp corner. If it is unavoidable, the paraffining helps to save the insulation.

Fishing.—To run a wire behind lath and plastering, a space between studding must be found by sounding with a hammer. There is a slight difference, which to the practised ear discloses the hollow chamber or space. To lead a wire through it, a hole is bored through lath and plaster. A piece of very flexible string is used for the "fishing." Well-waxed sail twine is excellent. Sometimes fishing line is used. Waxing is advisable for it also. To its end a weight is attached, for which purpose a few inches of No. 19 double jack chain is recommended. The flexible chain can be pushed through the hole, and doubling down will go through a small space. Often studs on a brick wall are only an inch thick, so that the chain is excellent for such places. A half dozen spherical lead bullets, bored and strung like beads, are better than the chain. With the weight at its end the cord is fed through the hole and goes down until it reaches the desired point, provided all is clear. With a plumb line or by the sound of the weight on the end of the cord the line is located, and a hole is bored through the wall or surbase or wherever it may be to meet it. A piece of wire with a short hook is inserted, and the cord is hooked by it and drawn out; the bell wire is attached to it, and is drawn back by the cord. This principle takes care of all vertical and often of inclined runs of wire. The wire can be drawn downward from the other end by the same cord.

Work Under Floors.—In running wire under the floor, a steel spring or flat wire 1/8 by 1/64 inch, with a hook at its end called a snake or fishing wire, is used. This can be pushed quite a long distance horizontally, and the string or the jack chain at its end, which has been dropped through a hole in the floor at some distant point, can be caught by a hook at its end and drawn back. If the beams run in the right direction or with the wire, it facilitates floor work greatly. If they run in the other direction, which is across the line to be followed, the wire must be taken through the beams one by one. A beam is located, and a hole is bored from the floor diagonally down from a point above its center. Floor beams are about a foot apart. If the string is dropped through a corresponding hole at the next beam, it is readily fished up to the surface of the beam in question. A

second diagonal hole is then bored, through the beam, so as to form an inverted V, and the cord is passed down it, to be fished up from the next beam. The process and result is shown in the cut, Fig. 538. The hole must be nicely closed by putty or plugs. For very particular work the holes must be kept as small as is consistent with gettting the cord and fishing wire through them.

This kind of work would not be allowed for fine-finished hard-wood floors, unless possibly a joiner would undertake to close the holes so neatly that the plugging would be unnoticed. Many cases would occur where this method would not be allowed.

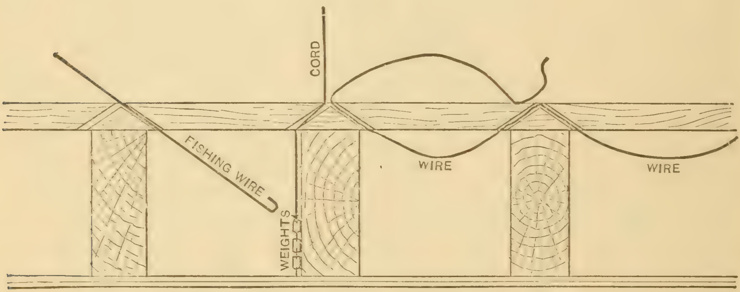


FIG. 538.—FISHING BELL WIRE UNDER FLOOR.

All sorts of expedients may be adopted. Houses differ from each other. Some have clear spaces running from plate to sill. If they can be found, a heavier weight, called a mouse, may be dropped at the end of a string, and thus one fishing will take a wire from base to top story. More will be learned by a few weeks with a competent man than by any description.

Moldings may be removed and the wires put back of them, grooves being raced out for the wires, or a corner may be planed off the lower inside corner of the molding to give room for the wire.

Racing is cutting a narrow groove in a floor or other wooden surface with a tool called a racing tool. It consists of a handle into which blades with hooked ends can be inserted. The groove

made is big enough to hold a wire. Sometimes wires can be laid in such grooves secured in place with tacks, but under existing conditions of house construction and furnishing this is not so often allowable as formerly, when floors were of soft wood and were fully carpeted.

Leading the Wires.—Exposed wires are used in some places, and are selected of color to match the paint or woodwork on which they lie. These can be stapled. The greatest care must be taken to keep them away from electric light wires. The distance between two parallel lines of bell wires should be half an inch, two wires never being put under one staple. Occasionally it may be necessary to adopt gutta-percha-covered wire for damp places, but this is not often the case. To splice wires, strip four inches of each and make the regular telegraph lineman's splice, as shown on page 508. If a very good job is to be executed, solder each joint, using no acid, but only rosin or some non-corrosive flux. The joints may be taped, but this is not usually necessary. If the joints are not well soldered, so that the solder fails to cover the copper, paper should be wrapped around them before taping.

Grounding Wires.—Some inches of the end are stripped of insulation and brightened by scraping or otherwise. They are wound around a gas or water pipe, the part being scraped or sand-papered. The place should be soldered. It is good practice to solder all grounded ends of the same system to gas pipes alone or to water pipes alone, and not to solder some to water pipes and others to gas pipes. In case of disconnection of a pipe system, the grounds will still be good. Thus bells could be rung during repairs to plumbing or gas pipes. The removal of the gas or water meter removes the water or gas system from the ground in great measure.

Soldering.—For soldering joints between wires a rather hard solder, one containing more than half its weight of tin, should be used. The soldering iron may be filed to the shape of a wedge with a groove filed across it, about ⅛ inch deep. The groove in the hot and well-tinned soldering iron is filled with solder. The twisted joining of the wires is dusted over with powdered rosin or other non-corrosive flux, and the groove full of melted solder

is applied to its under side. The iron is rocked back and forth and ultimately turned completely around the wire, or else the wire itself is turned around while in the groove. Soldering joints is not universal, but it adds to the quality of an installation.

In all cases before joining wires use emery paper or some equivalent on the ends, so as to brighten them and remove copper oxide and dirt and secure good electrical connection. Solder will not take hold of a dirty surface.

Wires.—Annunciator wire is double cotton-covered wire, with the cover saturated with melted paraffin. Office wire is a grade better in the quality of its cover. Sometimes wires are carried through tubes. As this brings them close together, wire of thoroughly good quality of insulation should be used in this case.

Distinguishing Colors may be used for different wires. This is a regular practice in other branches of work, and in bell work wires covered with different colored insulations can be used to distinguish the runs of wire. Otherwise, more or less frequent tagging of the wires can be adopted to make them readily traced through the house. As the tendency is now to use exposed plumbing, bell wiring should be done as much on the exposed order of work as possible.

CHAPTER XL.

ELECTRIC HEATING.

Electric Cooking and Domestic Heating is possible because the current need only be turned on a few minutes before it is needed, and can be at once turned off. If it were kept on by the day, the expense would be prohibitive. Various utensils require a certain period of heating before cooking can be begun with them. For an electric stove or griddle a period of 5 to 8 minutes is given; for a broiler, 12 to 14 minutes; for an oven, 20 minutes. The cooking operations proper are about the same as for coal fires. For boiling water, 15 to 20 minutes, and for heating flatirons, 8 to 12 minutes are required.

The cost of electric cooking in one experiment was found to be about five times that of coal cooking. All such figures are approximations only, as circumstances vary so greatly.

Power Required for Cooking.—A small broiler, 6 by 8 inches in area, will require from 340 to 400 watts, a 1½-pint kettle a little less; a 16-quart kettle, 1140 watts. A full electric range of 6 square feet area consumed 1650 watts per square foot of surface.

Efficiency of between 80 and 90 per cent can be attained in boiling water.

Electric Furnaces may be divided into two classes. In one the voltaic arc is the heating agency; in the other class incandescence is the principal source of heat. With many materials both arc and incandescence may operate simultaneously. The illustration, Fig. 539, gives a cross section of a simple electric furnace. The square box or case may be of iron. It is lined with some insulating refractory substance, such as lime or magnesia. Carbon rods pass through holes in the box, and are insulated therefrom as shown. To operate such a furnace a strong

alternating current is required. The carbons are connected in the circuit, and an arc is started across the interval between them. This may be done by pushing the carbons together, and thus closing the circuit. They are then drawn apart, and the arc

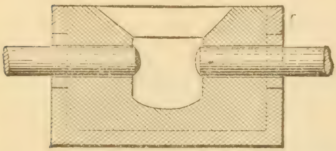


FIG. 539.—OPEN ELECTRIC FURNACE.

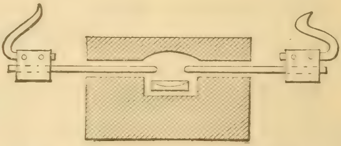


FIG. 540.—CLOSED ELECTRIC FURNACE.

is thus "struck" or formed. Material to be operated on is placed in the cavity, and as it reaches the level of the arc becomes heated by it.

Although this describes arc heating, it may often happen that when the material reaches the level of the carbons it conducts the current, and the furnace operates by incandescence.

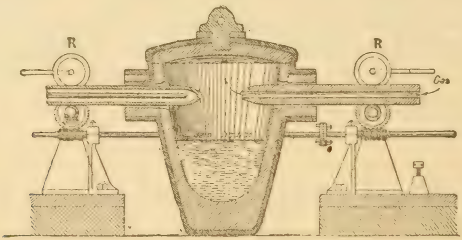


FIG. 541.—SIEMENS'S ELECTRIC FURNACE.

In Fig. 540 is shown an advance on the last. It is a covered furnace adapted to receive a vessel to be heated by the arc. In this apparatus, where the substance to be heated and the arc are distant from each other, there is no question of incandescence. The heat is due to the arc.

The furnace shown in Fig. 541 is virtually a lined crucible through whose sides two electrodes project. The electrodes are mounted so that they can be run in and out, thus varying the

length of the arc. Worm gear is provided for this purpose. One electrode is a carbon tube, the other is of metal and hollow, and water circulates through it, introduced by a pipe placed on its axis and reaching nearly to its end.

In the furnace shown in Fig. 542 a brick structure filled with

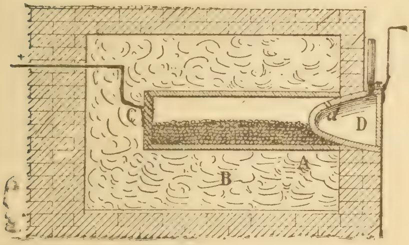


FIG. 542.—COWLES'S HORIZONTAL FURNACE.

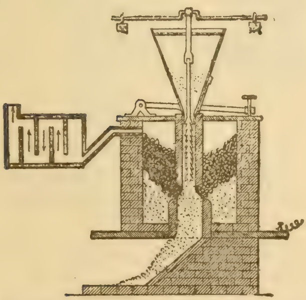


FIG. 543.—COWLES'S VERTICAL FURNACE.

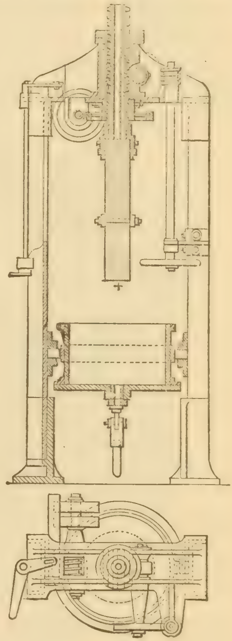


FIG. 544.—MECHANICALLY OPERATED ELECTRIC FURNACE.

non-conducting material, such as sand, B, holds a retort A. At the left end is a carbon electrode C, and at the other end is a carbon crucible which acts as the other electrode. The crucible D is perforated at *d* to permit the escape of any gas generated in the reactions.

The furnace of Fig. 543 has a hopper, through which material to be acted upon is introduced. From the bottom of the hopper a

tubular electrode extends downward, and a second one rises from the bottom, so as nearly to meet the other. Material can also be introduced from outside the upper tubular electrode. Gases which escape are condensed or cooled in a condenser, indicated to the right of the furnace. As the charge melts it runs down the central opening of the lower electrode and is withdrawn.

In Fig. 544 is given a section and plan of a more complicated furnace. In this structure the upper electrode can be moved not only up and down, but its end can be swung about over the area

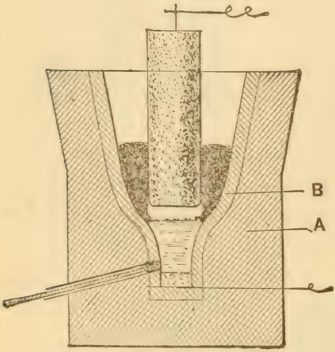


FIG. 545.—VERTICAL CARBON FURNACE.

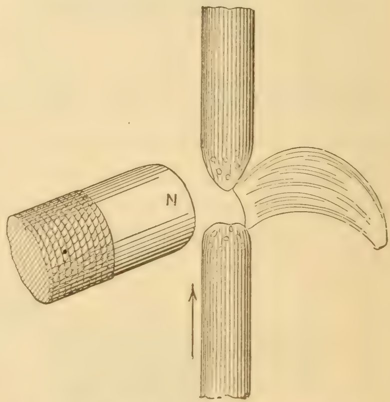


FIG. 546.—THE ELECTRIC BLOWPIPE.

of the crucible below it, so that all parts of the charge can be subjected to its action. The crucible is below the end of the carbon electrode, and forms itself the lower electrode. It is carried on trunnions, so that it can be turned down for pouring out its contents.

Another simple form of furnace is shown in Fig. 545. The crucible with its lining forms one electrode, and a carbon rod descends into its center from above, constituting the other electrode. Material enough may be added to cover the charge acted on and to supply new material as the materials melt down.

The electric furnace is a very simple thing. The factor absolutely necessary for it is plenty of electric power. The furnace

used in the manufacture of carborundum has sometimes been little more than a pile of coke covering the charge and held in place by a loose brick wall. Carbon electrodes entered the ends, and the current acting by incandescence heated the charge to white heat.

The Electric Arc Blowpipe.—The voltaic arc is repelled when a magnet pole is brought near it. This principle has been applied to producing an electric blowpipe, in which the arc driven to one side, as shown in Fig. 546, is used like a blowpipe flame for local heating.

FIG. 547.—ELECTRIC ARC HEATING.

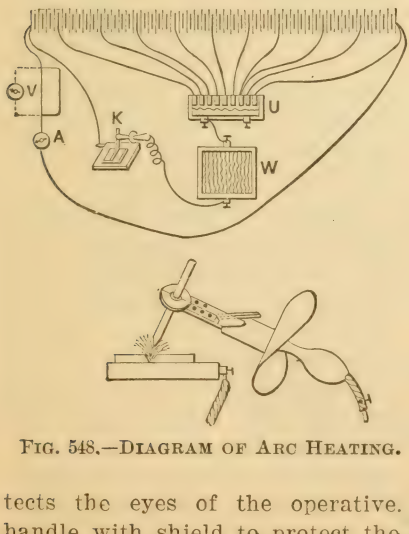
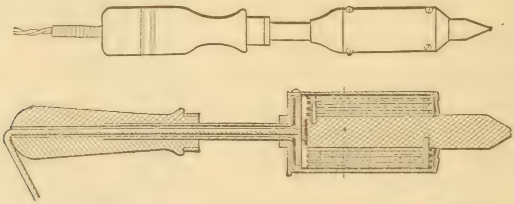


FIG. 548.—DIAGRAM OF ARC HEATING.

Direct Heating by the Electric Arc is carried out by making the object to be heated one of the electrodes of the arc. Thus, a boiler is shown in the cut, Fig. 547, as under treatment by the arc. One conductor is connected to it, the other is connected to a carbon rod carried in a holder and held over the point to be heated. An arc is caused to form, and is brought where desired by moving the carbon pencil over the spot. A colored glass screen protects the eyes of the operative. The carbon holder has a handle with shield to protect the hand, something like the hilt

of a fencing foil. A general diagram of the connections is given in Fig. 548. There is a storage battery, with a connection box U, by which the number of its cells supplying current to the arc can



FIGS. 549 AND 550.—ELECTRIC SOLDERING IRONS.

be increased or diminished. W is a resistance frame, and the carbon holder is at K. V is a voltmeter, and A is an ammeter. Below is seen the carbon holder with its protecting shield.

The Electric Soldering Iron, Figs. 549 and 550, uses less than red heat. The first figure shows the external view of one, and the lower figure is a section. The copper bolt is surrounded by a coil of wire insulated by fireproof insulation, which on the passage of a sufficient current keeps the bolt at the proper temperature for soldering.

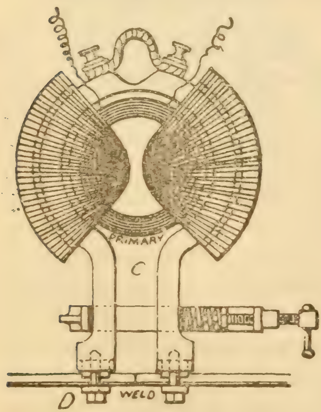


FIG 551.—ELECTRIC WELDING.

Electric Welding, the principles of which are shown in Fig. 551, uses the heat of direct incandescence. An induction coil or transformer has two coils, a high- and a low-tension one. An alternating current is passed through the high-tension coil, which induces in the low-tension coil a much more intense current than itself, but impresses a much lower voltage on the same circuit. In the cut the high-tension coil is the inner one lying flat on the paper, and the simple bar of iron outside it is the

low-tension coil. Wires are seen leading to the high-tension coil. These are connected to the source of supply. Two heavy coils of iron wire surround both coils and act as core. The pieces to be welded are held in the clamps as shown, and are rapidly

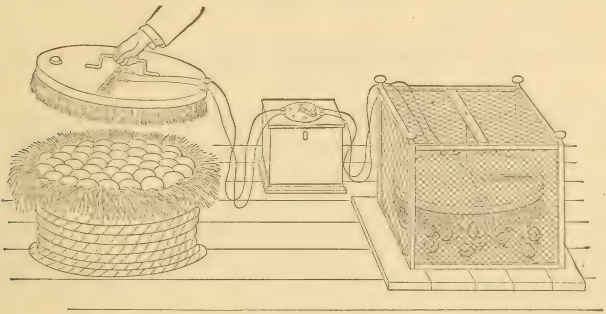


FIG. 552.—ELECTRIC INCUBATOR.

heated by the induced current. By the screw they are forced together so as to weld. Almost any conducting metal can be welded by this process. Very remarkable results have been attained with various metals and shapes.

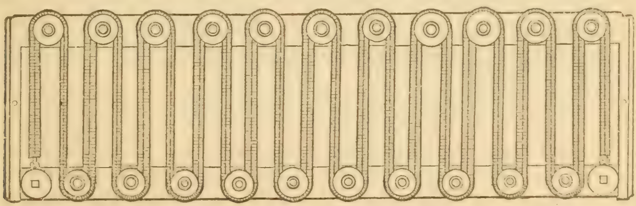


FIG. 553.—ELECTRIC RADIATOR.

The Electric Incubator, Fig. 552, is a curiosity in electric heating. A basket holds eggs and has a cover which contains a coil of wire, through which a current of electricity passes. By a thermometer the temperature is watched, and regulated by a resistance coil. The young chickens are kept in a coop which contains a heater to represent the mother hen. Both are shown in the cut, each with a thermometer on top.

Electric Radiator.—Many forms are made, consisting of long wire conductors which may be covered with asbestos insulation. The cut, Fig. 553, gives a simple form in which the conductor is carried up and down over studs on a frame. Iron and steel wire are good materials for the conductor. Their principal use is for heating electric cars.

Economy of Electric Heating.—When electric power is produced by a steam plant, the loss of energy is very great. By a law underlying the operation of heat engines, of which the steam engine is the most conspicuous example, by far the greater part of the potential energy of the fuel is wasted. From 90 per cent upward of the heat of the coal burned is lost. The law is termed the second law of thermodynamics. Under these circumstances the efficiency of electric heating is necessarily low. On the other hand, when water power is used for its production, it may be very efficient.

Its economy when produced by a steam-driven plant is low on its face, but is relatively high when intermittent heating is in question. The current can be cut off so readily that long periods of useless expenditure of fuel, inevitable in many cases of heating with coal, are avoided. The economy thus brought about compensates for the low efficiency explained above.

The electric heating of trolley cars is possible because the power is rather advantageously produced and the repairs of stoves are avoided.

CHAPTER XLI.

WIRELESS TELEGRAPHY.

Wave Transmission of Signals.—The ocean is thrown into waves by the motion of the air or winds. The particles of water in making the waves constantly move in vertical circles, round and round. The diameter of the circles is several times the height of a wave. The particles of water do not move forward or backward except through a limited range, and a wave on the deep sea does not transfer or carry water along with it. There is no displacement. A man at one side of a pond of still water could send a message to another by waves, if there was any good way of detecting them. The constant reflection and repetition of the waves would occasion trouble. But on a large stretch of water a sharp impulse given might send waves of water, which could be detected at a considerable distance. Such waves could be used to transmit messages. The air is thrown into waves of another type by the vibrations of bodies, and transmits sound. As air is much lighter than water, air waves travel at much higher speed than do water waves. About a thousand feet a second is the rate of sound transmission by air waves. The luminiferous ether is thrown into waves by various kinds of disturbances, electrical among others. Ether waves are transmitted with a velocity which would take them around the earth nearly eight times in a second. Air waves are the medium for propagating sound, such as the human voice. By wireless telegraphy ether waves are produced at one place and detected at another, and are made to transmit intelligence by the Morse code or some equivalent. The waves used are called Hertz waves, from the celebrated Prof. H. Hertz, an early demonstrator in this field. Their existence was predicated on Clerk Maxwell's celebrated electromagnetic theory of light.

If a discharge is produced between the terminals of an induction coil, a spark as it has long been called is produced. In reality this is an enormous multitude of discharges or sparks beating back and forth with decreasing intensity, but uniform frequency. The time occupied by the multiple discharge is very short, but the duration of a single element of it is in the second order of duration, and is almost infinitesimal. The discharge beating back and forth is called an oscillatory discharge. The time in fractions of a second of a discharge is calculated by the formula. $T = 2\pi \sqrt{KL}$; K being capacity and L inductance of the circuit. The oscillation in Hertz oscillators, as the special circuits for these experiments are called, varies from 10,000,000 to 300,000,000 per second. If it were possible to increase them to a sufficient frequency, light would be the result. The trifling light given by the spark is due to the heat of the discharge, not to its oscillations.

Hertz Receiver.—The oscillator transmits waves. As a receiver Hertz used a broken circle of copper wire. The diameter of the circle was about 16 inches. It terminated in little metal balls or knobs, whose distance apart was adjustable. When the oscillator was discharged, a minute spark passed across from ball to ball of the detector or receiver, when everything was in adjustment The receiver only operated at a short distance. At more than the length of a room the effect was too attenuated to produce a spark in the detector.

Branly's Coherer.—This investigator found that loose metal filings were astonishingly sensitive to ether waves of slow frequency, such as produced by oscillatory electric discharges. A tube containing loose metal filings and of relatively high resistance had its resistance greatly diminished by being held near the place where such ether waves could reach it. The ether waves make the loose filings take up a new condition and act in a degree like solid metal. As the molecules of every solid metal cohere, the tube of filings is appropriately termed a coherer. When once caused to cohere, the filings remained so until disturbed by agitation or otherwise. If such a tube is placed in circuit with a battery and relay, ether waves will by reducing resistance close the relay. If they cease, then tapping the tube will increase the resistance and open the relay.

Wireless Telegraphy is based on the production of an oscillatory discharge at a transmitting station, its transmission by ether waves through space, and the detection of the waves due to the discharge at the distant station. Originally only the coherer was used. It is still in extensive use, although many other receiving instruments have been invented. It is now sharing the work with other devices more rapid in action.

Transmitting Apparatus.—The principle of the Marconi transmitting apparatus is shown in the cut, Fig. 554. One or more vertical wires, W, are supported by a mast or other support. The lower ends, if there are several wires, are joined together and are connected to one ball, *d*, of a spark gap. The other ball, *d*, is connected to the earth. From *d* and *d* wires *c′ c′* are carried to an induction coil *c*. The primary of the coil with key *b* is in circuit with a battery *a*. On depressing the key, an oscillatory discharge takes place across the gap, and by charging and discharging affects the whole length of the vertical wire. Ether waves go off from the wire through space, with a general tendency to follow the curvature of the earth. They travel best over water, so that the ocean is peculiarly adapted for the use of wireless telegraphy.

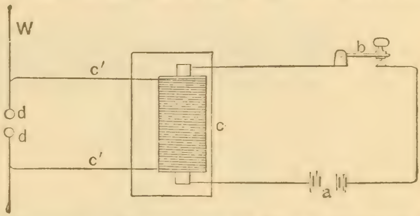


FIG. 554.—PRINCIPLE OF TRANSMITTING APPARATUS.

Marconi, beginning with vertical wires only twenty feet long, sent signals a mile. He found that increasing the length of the wire increased the distance of transmission, and the rule of the distance varying with the square of the length of the wire was at one time suggested, but has been abandoned.

Receiving Apparatus.—At the distant receiving station the system of antennæ is established, whose lower end is grounded with the primary of an induction coil in series. The secondary of the induction coil is in series with a battery and relay magnet. In parallel with the battery and relay magnet is the coherer.

Connection of Stations.—Referring to Fig. 555, 1 is the transmitting station with its antenna A_1, spark gap *b b*, induction coil secondary S_1 and primary P_1, sending key K, and battery B_1. On working the key, sparks pass between *b* and *b*, affecting the antennæ. Ether waves fly through space and are caught by the antennæ A_2 of the receiving station 2. The disturbance sends a momentary current through the primary P_2 of the induction coil. Its secondary S_2 then sends a current through

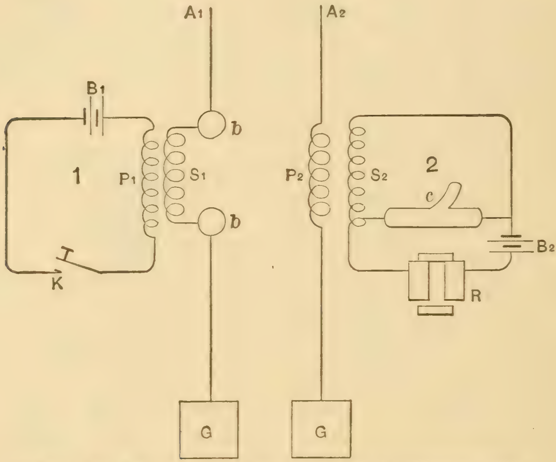


FIG. 555.—WIRELESS TELEGRAPHY CONNECTIONS.

the coherer *c*. This reduces the resistance of the coherer, and a current goes through it due to the battery B_2 and through the relay magnet R, operating a Morse receiver on local circuit.

There is a hammer which actuated by an electric magnet and make and break constantly taps the coherer, so that the coherer only retains its conductivity while acted on by ether waves. The instant they cease, the tapping restores its resistance. Long and short signals for the Morse code are sent by holding down the key K at the transmitting station for long or short periods. They are received by the receiving station and printed on a tape.

Marconi's Coherers.—Marconi's coherer, shown in Fig. 556, is a tube 1½ inches long and 1/12 inch internal diameter. A chamber is made in the center by introducing two silver plugs with their ends 1/30 inch apart. A mixture of 90 per cent nickel filings and 10 per cent silver filings is contained in this space with a minute quantity of mercury.

Hysteresis and Other Receivers.—The coherer used as a receiver operates a relay circuit, and prints the message on a tape in Morse characters or their equivalent. This has the advantage of giving a fixed record. There are a number of receivers which do not give a record, some of which are based on magnetic lag. The hysteresis of iron is modified by ether waves impinging on it. In one of Marconi's receivers an end-

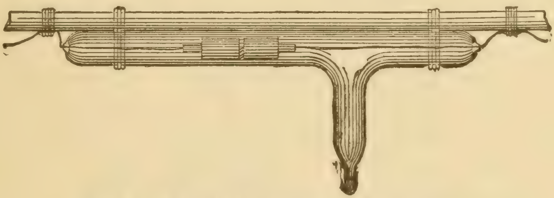


FIG. 556.—MARCONI'S COHERER.

less iron wire is stretched around two pulleys, and passes through the core or axis of a double coil of insulated wire. The arrangement represents an induction coil with moving core. The primary receives the impulses from the receiving antennæ as already described. The secondary connects with a telephone receiver. The impulses modify the hysteresis of the moving core, and sound is produced in the telephone. In another construction the core of the induction coil is fixed, and an electro-magnet rotates in front of it. The ether waves modify the hysteresis as in the case just cited, and the message is received by a telephone.

There are a number of other constructions of receiving instruments in which a telephone is used as a receiver, the great sensitiveness of the telephone receiver causing them to be operative. The action of the ether waves on these classes of instruments is so slight that the instruments can only be

used with a telephone receiver, and cannot actuate a printing recorder. On the other hand, the acoustic instruments are faster, other things being equal.

Detectors.—When an impulse from a distant station is received on the receiving antennæ or aerials of a station, it has to be rectified or otherwise affected in order to be heard on a telephone. A number of instruments have been invented to do this, and the name detector has been given them. The currents dealt with are so exceedingly minute that the construction of rectifiers is based to an extent on principles which would not be applicable to large currents. The name detector is also applied to coherers and other apparatus and appliances, and even to simple spark-gaps, in which there is no rectification of current.

Italian Navy Coherer.—This consists of a small glass tube with two iron plugs, between which plugs is a drop of mercury. The mercury only makes good contact with the iron when the ether waves act upon it. It is self-decohering. It resembles the Branly instrument, and is used in the same relation to the aerials.

The Lodge-Muirhead Coherer.—This is also self-decohering or restoring. A small steel wheel with a sharp edge is rotated by clockwork, and just touches the surface of a globule of mercury, which is held in a cup on the top of a brass pillar. A thin film of oil is maintained over the surface of the mercury. The oil insulates the wheel from the mercury so that no current can pass, unless the apparatus is excited by a discharge. The apparatus is put in a local circuit, as in the case of any coherer. When electrical oscillations are set up in the receiving aerials, the insulation of the oil breaks down and a local current can pass and actuate the receiving instrument. The constant rotation of the wheel decoheres it when the impulses cease, its rotation representing in a sense the tapping of the Branly coherer. No relay is required with this instrument; the resistance is so low that it can operate a recording apparatus directly.

The Stone Coherer has steel plugs with loosely packed carbon granules between their end faces. It is self-decohering.

It is lacking in sensitiveness, but is well adapted to be used in portable outfits, as it is not easily put out of order or adjustment.

The Fleming Valve Detector.—A small incandescent lamp has a cylinder of copper surrounding its filament; it is kept incandescent by an independent circuit. Besides this the negative terminal of the filament is connected to one terminal of the telephone receiver. The other telephone terminal connects to the copper tube by a platinum wire sealed into the

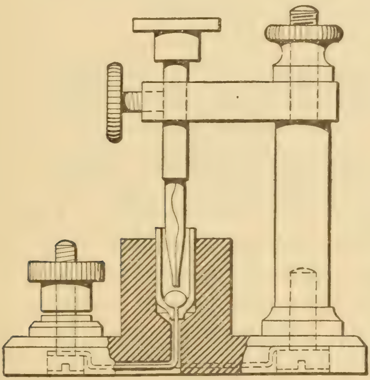


FIG. 557.—FESSENDEN DETECTOR.

lamp bulb. When acted on by the discharge from the aerials the copper cylinder is alternately charged with positive and negative electricity. Electrons are constantly being emitted from the filament; they are repelled when the cylinder is at negative potential, but when at positive potential they are attracted by it. This attraction and reception of electrons constitute an electric current, and from what has been said it is obvious that it can only pass in one direction. Hence it is a true rectifier, and gives a current which can operate a telephone.

Electrolytic Detectors.—There are a number of these based on the same principle. The following gives the general fea-

tures of the Fessenden detector. An exceedingly fine platinum wire is sealed into a glass tube so that only its minute end is exposed. This is immersed in a solution of 1 part sulphuric acid to 5 parts of water. A globule of mercury or a plate of silver lies below the platinum also in the acid. This constitutes a small electrolytic cell; silver or mercury and platinum have each their own terminal, and it is connected in series with the receiving telephone and a source of current. The platinum point is at once polarized. When the oscillations from the receiving aerials are passed across such a cell they depolarize the platinum electrode. This enables a current to pass, for as long as the platinum was polarized it cut off the passage of current. Thus the successive impulses of discharge depolarize the platinum and current passes; when they cease the polarization takes place again and current ceases. The telephone answers to the changes and gives a note, and can receive a message. It is believed that the action may be more complicated than the above; resistance, charge and counter-electromotive force it is believed may play a part.

Heterodyne Detector.—This device is also due to Fessenden. It is based on a very simple and obvious principle. If the discharge from the aerials is received in a telephone it is of such high frequency that no sound is produced. Now if simultaneously with it a second coil on the telephone received a local current of slightly less or greater frequency, interference would result and the beats could be made to occur at any desired frequency, so that the telephone would react to them. Thus suppose the discharge had a frequency of 50,000 per second. This would be without effect on a telephone. Suppose that the second current had a frequency of 49,000 or of 51,000 per second; the result would be the production of 1,000 beats per second. This is a good telephone pitch. Thus as long as the discharge lasted the telephone would sound by the beats of the interfering waves. When the current alone passed the telephone would not speak. This instrument has very high power as regards receiving from great distances.

Goldschmidt's Tone Wheel is a mechanical rectifier. It is simply a toothed wheel, and the discharge goes through it by

brushes making contact with its teeth. It is obvious that it is a simple matter theoretically to adjust its speed of rotation so that there is contact for each wave. When the brushes are between the teeth no current can pass; therefore only half the current can pass, and the adjustment is such that this is all in one direction. The other portions of the waves are cut off. This receiver has been used successfully on transatlantic work. The adjustment to a given high frequency is far from simple practically. But if a slight slip is allowed to the wheel, it is obvious that it will work in a manner analogous to that of the Fessenden device just described. It will gen-

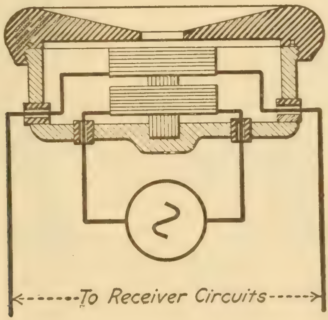


FIG. 558.—HETERODYNE DETECTOR.

erate a wave of good telephone frequency when the difference in frequency between it and the discharge is correctly determined.

Crystal or Contact Detectors.—There are a number of these used most extensively in practice. They are rectifiers, based on the principle that many natural or artificial minerals will only pass current in one direction. Suppose a crystal of carborundum, artificial aluminum silicide, is placed in the circuit of a current. In one direction the current may be 100 times stronger than in the reverse direction. Silicon, galena, iron pyrite, zincite, and molybdenite are some of the substances which have been adopted for practical work. There

are all sorts of details in the connections of these detectors, but the principle is simplicity itself. They give directly a one direction current for the telephone when acted on by the oscillating discharge from the aerials.

Spark Gaps.—There are many kinds of spark gaps. One of the simplest of the commercial ones consists of a pair of hemispheres, often made of zinc, and protected from leakage by

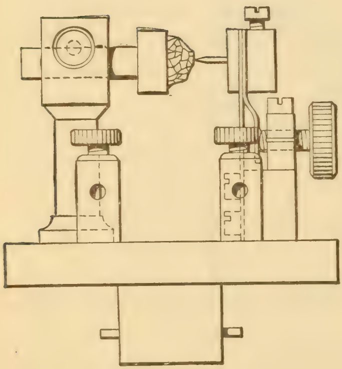


Fig. 559.—Single Crystal Detector.

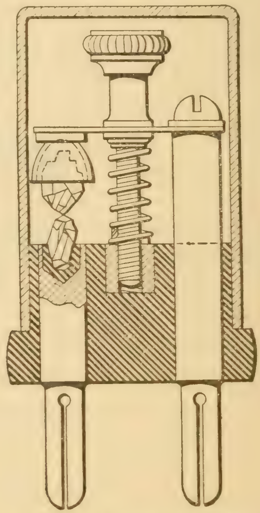


Fig. 560.—Double Crystal Detector.

discs extending from their peripheries. To adjust them, their distance apart is varied, and to prevent damage to the apparatus a pair of terminals at a fixed distance are arranged directly below them, between which a spark may pass, if the tension rises to too high a point. The protecting discs are not found on all this class of gaps.

The Disc Discharger is a rotating disc, with teeth. On each side are electrodes, and sparks pass as the teeth go by the electrodes. The apparatus is quite complicated, the above giving merely the basis of its construction. The Telefunken

quenched spark is produced by a series of discs, arranged cylinder fashion, insulated from one another by mica. The discs are of copper faced with silver plates, and the discharge goes through the series as a set of sparks, which may be eight in series.

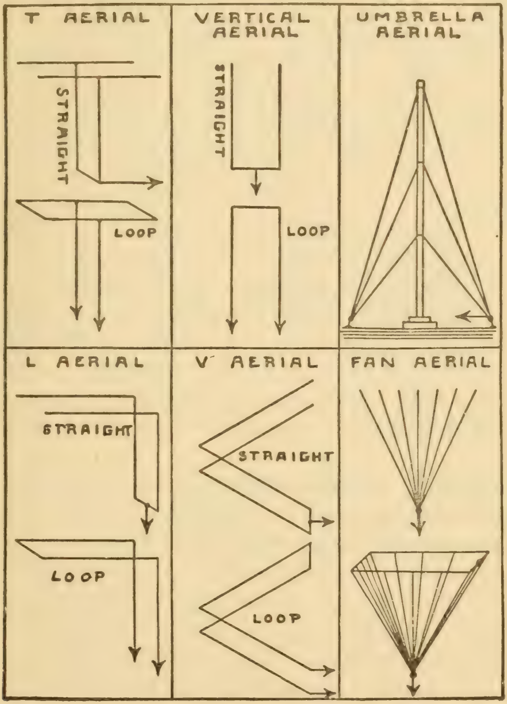


FIG. 561.—AERIALS OR ANTENNÆ.

Aerials or Antennæ.—There are some six prominent classes of aerials. The illustration shows them and is self-explanatory. The arrowheads indicate the grounding. In some large stations most elaborate and complete grounding is provided by burying zinc plates and connecting the leads thereto. The higher an aerial is the more power will it have as regards

distance or range of action. The same applies to size; the larger it is the more powerful will it be. The all-important thing is that there should be plenty of metal surface, and stranded conductors are used to insure this. Bronze or copper wire is generally employed. The distance apart of the constituent wires is important to avoid self-induction in the horizontal leads; a distance or interval of five or of ten feet is standard practice. The highest power of transmission is in a direction parallel to the horizontal component of the aerials. By carrying out this feature to the greatest possible extent, directional systems are produced, which tell the direction of

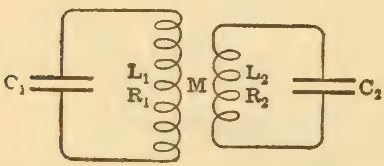


FIG. 562.—MAGNETIC OR INDUCTIVE COUPLING.

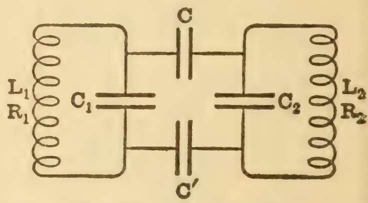


FIG. 563.—ELECTRIC OR CAPACITY COUPLING.

the transmitting system. This is, among other cases, peculiarly applicable to airplane navigation over the ocean.

Couplings are the connection between the two or more elements into which a receiving or a transmitting circuit can be resolved. Of these two parts one is in each case the aerial or antennæ, the other is the circuit containing receiving or transmitting apparatus. These divisions are called also systems, and coupling is defined as the arrangement of two systems, so that oscillations in one of the systems always causes oscillations in the other.

Conductive Coupling is when the two systems are in actual metallic or conductive connection. It is also called Direct coupling and Galvanic Coupling; a pure conductive or galvanic coupling must have no mutual inductance between the two systems.

Magnetic or Inductive Coupling is so arranged that the only connection between the two systems is by mutual induction.

This connection is established by means of two coils with parallel axes, one in each system, which coils react on one another when there is any change in the magnetic field of either one. It is shown in the diagram.

Electric or Capacity Coupling is obtained by having one or more condensers common to the two systems. An electric disturbance in the one system reacts upon the other by the agency of the condenser or condensers. This is also shown in diagrams.

Combined Couplings are produced by having two of these couplings in the same system.

Loose and Close Couplings.—These are terms of a descriptive nature indicating that couplings are so arranged that in the one case (loose coupling) a slight reaction only occurs between the two systems, and in the other case (close coupling) a strong reaction occurs between the two. The strength of the reaction is increased in a magnetic coupling by bringing the inductive elements of the two systems closer together, and vice versa. In a galvanic coupling, the larger the common portion of the two systems the closer will their coupling be.

Marconi Sending Plant.—The connections used in this plant are given in the cut. *A* is an alternating current generator. *K* is the sending key; *B* is an induction coil with iron core, to tune the system to the frequency of the current. *C* is a step-up transformer, transforming the voltage of the alternator up to 15,000 or 20,000 volts. This produces an inductive coupling. D_1, D_2 are choking coils, without any cores, designed to protect the transformer from high frequency oscillations. Next comes the oscillation circuit, which includes the rotary spark-discharger, *E*, which regulates the frequency of the system from 50 to 300 periods per second. It also contains a variable condenser, indicated by the two parallel lines with a diagonal arrow, and a variable inductance, *F*, which is used to tune the circuit to the desired frequency. Another transformer makes inductive coupling with the aerials, which in their turn are provided with a tuning inductance, *H*, and an earth arrester, *O*. The latter, shown in the cut, is essentially a short spark-gap, too short to insulate the antennæ in send-

ing, on account of the high potential of the circuit, but which resists the passage of the oscillations as received from the distant station from going to the earth. Thus it acts as a

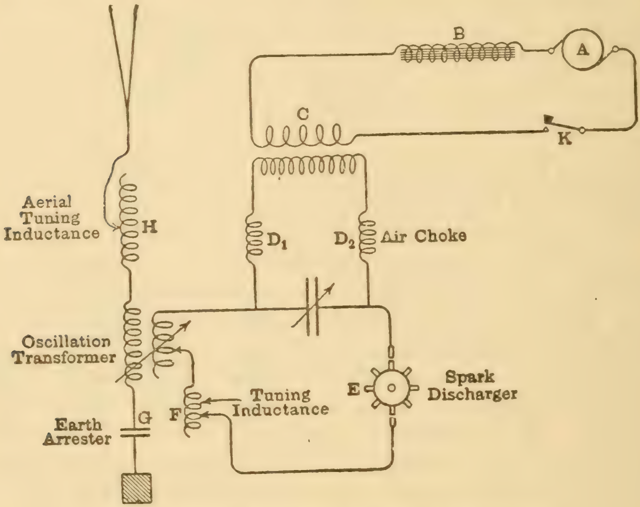


FIG. 564.—MARCONI'S SENDING SYSTEM.

sort of valve. The sparks pass from the outer edge of the upper plate to the surface of the lower and larger plate. The sparks are about 0.01 inch long, their length being determined by the thickness of the mica.

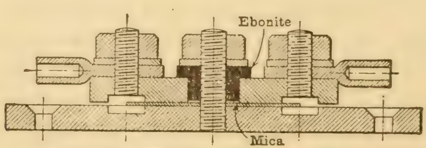


FIG. 565.—MARCONI'S EARTH ARRESTER.

Marconi Receiving Plant.—This portion of the apparatus is connected in shunt to the earth arrester, *G*, and after what has been said the cut will be almost self-explanatory. *H* is the

aerial variable inductance, C is a variable condenser, D a variable inductance, and E is a transformer, giving a coupling to the next circuit, X, which circuit in its turn is coupled, also

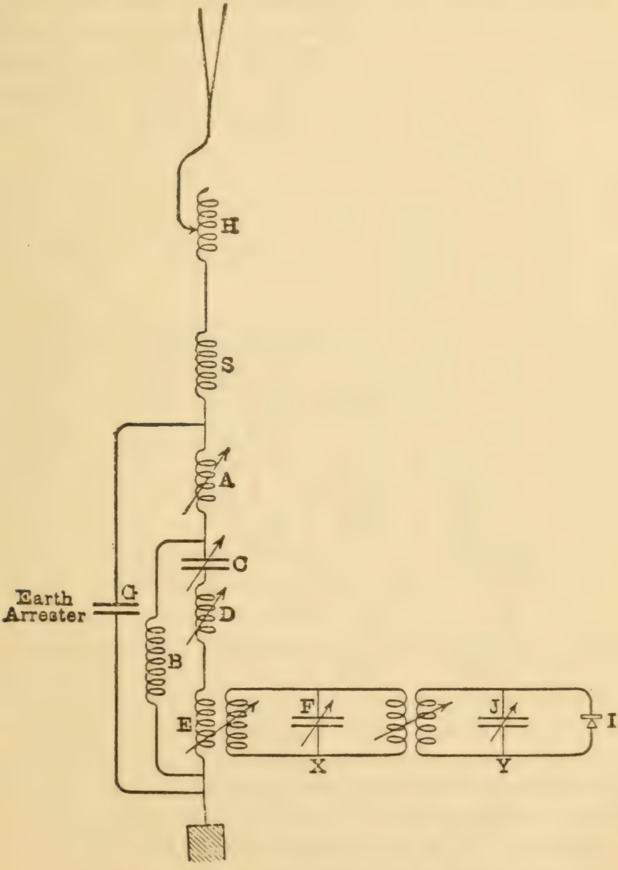


FIG. 566.—MARCONI'S RECEIVING SYSTEM.

inductively, to the listening or receiving circuit, Y. F and J are adjustable condensers, and I is the detector. The listening telephone is not shown; it may be connected in parallel with

the detector. *B* is a choking coil which takes off static charges from the antennæ.

Enough has been given to enable the reader to form a general conception of wireless telegraphy. The subject is one of great extent, its development is going on rapidly, and it is in a constant state of change. The mathematics of the subject are enough to constitute a treatise. It cannot be adequately treated in as few pages as we are at liberty to devote to it here. The same applies to wireless telephony.

Wireless Telephony.—A number of systems of wireless telephony have been invented, based on various principles, and so numerous that it is beyond the scope of this book to do more than give an outline of some of the basic principles underlying the typical ones.

Suppose that a stream of radiations is emitted from the antennæ of one station, such radiations to be constant in amplitude and in frequency, the frequency to be several thousands per second. Such emanations received by a receiving station will produce no sound in a telephone, although the diaphragm will respond to them, as the pitch will transcend the range of audibility of sounds. A microphone is connected in the sending system in such a way as to change the resistance or the capacity of the antennæ, directly or by magnetic or static coupling, as such microphone is acted on by the human voice. At the outset there are two different ways of affecting the emanations; the amplitude of the waves emanated may be made to vary, or their wave length may be altered by the action of the microphone. The emanations are changed by the action of the microphone from a steady stream to a varying one, whose variations are proportional to the vibrations impressed on the microphone by the voice; therefore when this varying stream of emanations is received on the distant antennæ of a receiving station, the variations impressed on the telephone connected to the antennæ reproduce the words spoken at the transmitting station.

The microphone may be used in a large variety of ways. It may change capacity or resistance of the antennæ, it may vary the excitation of the generator supplying the basic cur-

rent, when such is used; if an arc is used to give the basic current, it may affect the action of the arc in a number of ways; and the action may be such as to simultaneously affect the amplitude and the frequency of the current.

Sending Arrangement for Wireless Telephony.—Referring to the cut *M* indicates a microphone, connected in series with the antennæ. A continuous arc is maintained as shown to the left of the diagram, between a copper and a carbon elec-

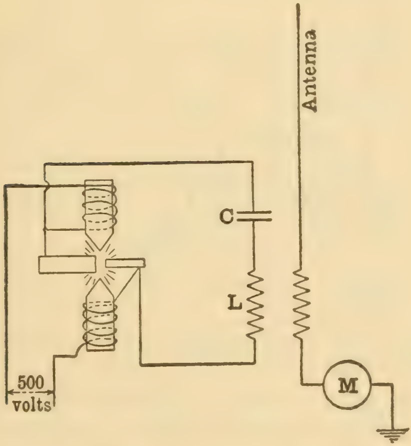


FIG. 567.—SENDING ARRANGEMENT FOR WIRELESS TELEPHONY.

trode in a magnetic field and in an atmosphere of hydrogen gas. This is the Poulsen arc. The resistance of the microphone varying with the action of the speaker's voice, impresses the steady oscillations due to the arc with the varying oscillations due to the voice, so that a set of speaking undulations is sent out through space, to be picked up by a distant station. The coupling as shown at *L*, is an inductive one. The microphone could be placed in the arc-circuit, it could be used to change the action of the arc, and could be made to produce a speaking emanation in several other positions or connections than the one indicated in the cut. Thus *C* indicates a con-

denser which determines the capacity of the arc circuit. The microphone can be so constructed as to change the capacity of the circuit it is connected in, and thus to statically affect the undulations of the emanations and produce a speaking current.

Receiving Arrangement for Wireless Telephony.—In general principles this is simple; there is no question of variations

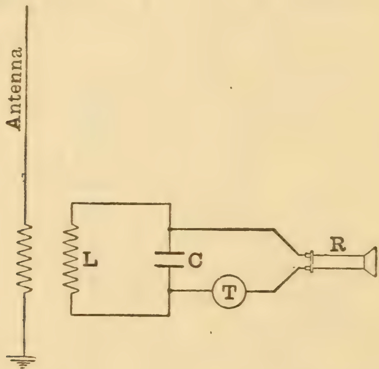


FIG. 568.—RECEIVING ARRANGEMENT FOR WIRELESS TELEPHONY.

such as are met with at the transmission end; the cut gives the outline of the arrangement, which, of course, is subject to various changes.

The antennæ receive the undulations; by inductance at *L* they are impressed on the coupled circuit as indicated in the cut; *C* is a condenser, and in parallel with it is a circuit containing a detector, *T*, and a telephone, *R*. The listener at the telephone hears the distant talker at the transmitting station.

CHAPTER XLII.

METALLIC FILAMENT INCANDESCENT LAMPS.

Metallic Filament Lamps.—Various metals have been employed in incandescent lamps. Platinum was one of the first metals tried, but it was too fusible. Tantalum met with some degree of success, but tungsten, a metal of the iron group, is the survivor of all. One great advantage of metallic filaments is that the illuminating power of the lamp is not affected by changes in voltage to anything like the same extent as in the case of the carbon filament lamp. A change of one per cent in the voltage supplied to a carbon lamp effects a change of six per cent in the light. If a carbon filament is charged with a metal, or metallized, as it is termed, the corresponding change is less than five per cent. It is still less in the case of a full metallic filament.

Tungsten Filaments.—Tungsten is a metal of the iron group, very infusible and abundant in nature. Several ways of making filaments of this metal have been employed. The starting point is powdered tungsten. It may be mixed with a moist binding material, squirted through a die, and heated in a reducing atmosphere, such as hydrogen. Another process is to heat it to a high temperature and weld the powder together by pressure or percussion. In the amalgam process 40 per cent of the powdered metal is mixed with an amalgam of equal parts of cadmium and mercury, the mixture is forced through a die, and heated to expel the cadmium and mercury. The wire thus produced is quite flexible and ductile. The electro-plating process is based on coating the wire with gold, silver or some other metal, which protects the tungsten from oxidation during treatment. Finally the thorium process, following the lines of the Julian Pintsch invention, is now much

used. The ordinary tungsten filament is very brittle and crystalline. To apply this process the tungsten oxide is reduced to the metallic state by ignition in hydrogen. The powder thus obtained is mixed with thorium oxide; two per cent is specified in the patent. A very little binder is added and mixed with it, the soft mixture is squirted through an aperture or die, is dried and passed slowly through a tube. A current of hydrogen gas is maintained through the tube, and in the tube is a coil of tungsten wire, kept at a high heat. The filament is passed very slowly through the length of the tube, and as it emerges therefrom is of high tensile strength and has lost its brittle, crystalline nature. It is of 164 kilogram tensile strength per square millimeter. The thorium seems to lengthen the crystals.

Sometimes as much as 50 per cent of thorium oxide is employed. An addition of 20 per cent operates to increase the resistance of the resulting filament 50 per cent. More than 50 per cent of thorium oxide gives a high resistance material which is brittle, but which makes it possible to employ a short filament.

One square millimeter of surface of the tungsten filament gives 0.5 candle at 0.55 watt to the given area. The carbon filament gives 0.182 candle at 0.63 watt. The light given by the carbon filament varies with the 6.3 power of the voltage; that of the tungsten filament with the 3.6 power of the voltage.

The dies for drawing tungsten wire for filaments are now made of high-speed steel or of diamonds.

Tungsten is the most refractory of all metals, but it melts at a temperature far below that at which carbon fuses, and far above the temperature at which carbon volatilizes. In general the limiting temperature at which metal filaments can be used depends on their melting points, and that of carbon on its volatilization point. Once a metal filament lamp bulb begins to blacken the process is very rapid, although it is generally a long while before it begins. Carbon on the other hand is apt to begin to obscure the bulb earlier and to take a much longer time to do it.

Gas-filled Incandescent Lamps.—In the early days of elec-

tric lighting attempts were made to use a glass bulb or tube filled with nitrogen gas to hold the incandescent carbon rod or filament. This was discarded in favor of the vacuum, which for many years was in universal use for carbon filament lamps. To-day it is used for both metallic and for carbon filament lamps. For the latter the vacuum is the only available way of preventing the burning of the carbon. Tungsten filament lamps now are frequently filled with gas. For large lamps nitrogen gas is used; for small lamps argon is sometimes employed; a little nitrogen is mixed with it to help it to resist a discharge. Argon has a lower conductivity for heat than nitrogen, and therefore prevents the bulbs getting overheated. A tungsten filament in a vacuum-bulb, if heated too intensely, or sometimes by proper heating long prolonged, throws off a discharge of metallic vapor, which plates the bulb and obscures the light. If the bulb is filled with gas this discharge is in great part prevented. Any which does occur is carried up to the top of the bulb by the gas currents in the bulb, set up by convection, and deposited there where it does little harm. Owing to the cooling effect of the gas, a greater current is needed to operate a gas filled lamp, but on the other hand the filament can be heated to a much higher temperature than in the vacuum. This restores the condition of economy. A thin filament exposes a proportionately larger cooling surface than a thick one. Hence to avoid too great cooling effect from the gas filling, the filament is made thicker and shorter, and a heavier current is required than for the vacuum lamp filament.

Leading-in Wires in Incandescent Lamps.—Instead of platinum, for many years the only metal used for leading-in wires, a compound wire, **dumet wire**, is used to pass through the glass of the incandescent lamp. As the glass has to be soldered or melted around and must adhere to the wires, they must be of as nearly as possible the same coefficient of expansion as glass. As platinum has such a coefficient it was for many years the only metal used for this purpose. Dumet wire, presumably meaning two-metal wire, consists of a core of an alloy of 45 per cent nickel and 55 per cent iron; within a

sleeve or coating of copper surrounding it. Copper expands much more than the iron-nickel alloy, and much more than glass; the high coefficient of the one works against the low coefficient of the other, with the result that the expansion of the compound wire is almost the same as that of glass, and it solders perfectly into the bulb. The filament is attached to it by spot welding or some equivalent method.

The Auer Process of Attaching Metallic Filaments to the leading-in wires is as follows: The filament is secured a short distance below the ends of the leading-in wires; one end of the filament to one of the leading-in wires. An arc is then started through the space between the ends of the leading-in wires. The ends instantly fuse, forming beads or little balls of the metal, and these balls run down the ends of the leading-in wires and melt around the ends of the filament. The arc is at once short-circuited when this takes place.

Molybdenum Supports of Filaments.—The upper supports attached to the glass stem inside a tungsten lamp are now largely made of molybdenum. As the wire of the filament is put in they are made to spring down a little under the strain, so as to keep the filament tight if it lengthens.

Duration of the Tungsten Filament's Efficiency.—After a thousand hours' burning it was found that a tungsten lamp had only lost 3 per cent to 4 per cent of its candle power.

Photometering Gas-filled Lamps.—The spinning or rapid rotation of an incandescent lamp on the photometer, so as to obtain an average candle power, is liable to give inaccurate results in the photometry of gas-filled lamps. The convection currents of the gas filling of the bulb are undoubtedly disturbed, so as to introduce conditions not present in the lamp when in regular use. For each lamp, however, there is a speed of rotation, which gives correct results on the photometer; this has to be known or determined to employ the rotating apparatus and get the average candle power directly and simply. This correct speed exists for most gas-filled lamps.

Overshooting.—This term describes the quick attainment of its full brightness by a tungsten filament lamp. The cold

filament is of much lower resistance than is the hot one. Hence at the first instant of turning on the current a heavier current than the lighting current passes and brings the filament up to white heat with what may be called undue rapidity. A tungsten filament in series with a carbon one is more quickly brought to incandescence.

In the action of overshooting the momentary candle power is higher by about 20 per cent than the normal. This high power only lasts for an instant.

Helion Filaments.—This is a filament of silicon, with a slender carbon filament as a base for its production. The carbon filament is heated or flashed in an atmosphere of silicon fluoride or some gas containing silicon and decomposable by heat. The filament thus treated becomes coated with silicon and is of very high efficiency, running as high as 1 watt to the candle power, and resists a very high temperature before softening.

Metallic Carbon Filaments is the name of such as have been subjected to a special heating treatment. After the regular flashing in a hydrocarbon the filament is exposed for several minutes to a very high temperature, nearly that of the evaporating point of carbon, which causes the shell of the filament to acquire metallic properties, such as low electric resistance, positive temperature coefficient of resistance, metallic lustre and low vapor tension. It can be operated at a temperature high enough to give an efficiency of 2.5 to 2.6 watts to the candle power.

Osmium Filament Lamps.—This metal of the platinum group was one of the first metals experimented with as a material for filaments. Its conductivity is inconveniently high. In Germany three were put in series on a 110 volt circuit, giving about 27 volts for each lamp. Their efficiency was high, 1½ watts to the candle power. They were almost untransportable on account of the high fragility of the filament. Although one pound of the metal will make 30,000 filaments, it is estimated that there is not enough of the metal known to exist to supply incandesecnt filaments for one year of consumption.

Tantalum Filament Lamps.—This metal, with a fusion point of about 2,250° to 2,300° C. (4,018° to 4,108° F.) has been experimented with as a filament. Its specific gravity is from 16.8 to 17. To prepare it its oxide is treated in an electric furnace in vacuo, and melted, giving a button of the metal, which is drawn into wire of extreme fineness. Thus prepared it compares with steel in strength, but gradually becomes brittle in service. At first it lengthens so as to hang somewhat loosely in the bulb, but it next grows shorter and strains at its supports. Its efficiency is 1.8 watts per candle power. A typical filament for a 22 candle power lamp is 25.6 inches long. 0.002 inch in diameter, weighing so little, that although the metal is expensive, the question of cost was taken as eliminated.

CHAPTER XLIII.

VACUUM TUBE LAMPS, FRAME ARC LAMPS, NOTES ON ILLUMINATION AND PHOTOMETRY.

Vacuum Tube Lamps.—These lamps have been extensively experimented with and now are reduced, as far as practical results are concerned, to two kinds: One is the McFarlan Moore lamp, now used for color comparisons, and in other ways to a rather limited extent, and the other is the Cooper-Hewitt mercury vapor arc light, a vacuum tube charged with mercury vapor, and which is being extensively used for factory and outdoor lighting installations. The McFarlan Moore lamp is really a Geissler tube. In the Cooper-Hewitt lamp the heavy mercury vapor gives characteristic effects, which differentiate it from the Geissler tube, as usually understood, although it is, properly speaking, a mercurial vapor Geissler tube.

The Cooper-Hewitt Mercury Vapor Lamp consists of a tube, exhausted of air or other gas, and containing some mercury. It follows that it is filled with a small amount of gaseous mercury, the amount of which will vary with the temperature. The tube is held in a vertical or inclined position, never in a horizontal one. The reason for this will be understood from the description. At the lower end is a pocket of mercury, and into this mercury a wire terminal extends or is in contact with it. The wire goes through the end of the tube and is sealed in the glass. This is the positive electrode. At the upper end of the tube, through which a wire also extends, sealed in the glass, there is an electrode, cup-shaped, made of thin iron, and connected to the wire. If a current of electricity is caused to pass through the tube a bright light is produced. Owing to the inclined position of the tube any mercury which condenses on the walls of the tube runs back to the positive electrode. Thus the tube is never obscured with globules of mercury, and the electrodes are kept in

proper condition. As the lamp is designed to operate upon an incandescent lighting circuit, it is obvious that the first problem is the starting of the arc.

Starting the Cooper-Hewitt Arc.—Each tube is provided with an auxiliary apparatus, which steadies the light and also operates in the lighting of the lamp, or what is the same thing, the starting of the arc. This apparatus is generally mounted above the tube. If for a direct current system it contains a resistance coil in series with an electric magnet. If

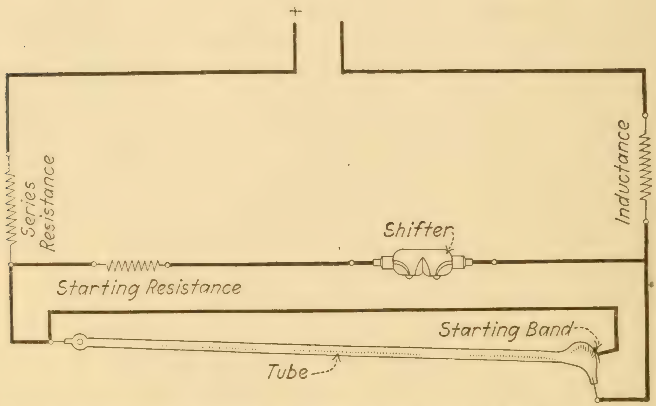


FIG. 569.—COOPER-HEWITT MERCURY VAPOR LAMP AND CONNECTIONS.

for an alternating current system a choke coil occupies the place of the resistance coil. Near the poles of the magnet there is mounted a mercury switch called a "shifter." This is a small receptacle of glass, carried on pivots, and with an armature attached to it. It contains mercury in contact with two wires sealed in the glass. In its natural position the mercury connects the wires, thereby short-circuiting the lighting tube or lamp proper. With the apparatus connected and the mercury switch in its natural position, if the current is turned on, it would go through the resistance coil or choke coil and then through the magnet coils, and so out to the line again. But suppose the mercury coil is free to oscillate,

or rotate in its bearings, which it is arranged to do. Then when the current is turned on, it starts through the coils, as just described, excites a magnet, which attracts its armature, causing the mercury switch, "the shifter," to rotate and assume a new position, opening its circuit and bringing the lighting tube into the circuit. This breaks the main circuit, producing an induced discharge of such high potential that it jumps the length of the lighting tube, starts the mercury arc, and thereby puts the lamp into operation.

Cooper-Hewitt Tube.—The tube is made of lead glass, and of various lengths, as given in the table. It must be chemically clean in its interior, and before receiving its charge and before exhaustion, is cleaned with acid and potassium bichromate. The iron electrode must also be free from all extraneous matter. It is about three-quarter inch in diameter, with rather thin walls. To its interior, at the lower or mercury end there is attached a patch of about a square inch area of carborundum. This supplies a multitude of points, and such are favorable to an electric discharge. The outside of the same end is coated with tin-foil. This along with the mercury provides a sort of Leyden jar, or condenser, to intensify the starting discharge; as the tin-foil is connected to the positive electrode, while the mercury inside the tube is in contact with the negative electrode, the condition of a static condenser or Leyden jar is produced. The tin-foil is called the "starting band."

Visual Acuity.—This term is now much used in discussing artificial illumination. It means simply sharpness of vision or the relative ability to see things. There is a certain amount of chromatic aberration in the optical apparatus of the human eye, and the theory is maintained by the advocates of the monochromatic type of lamp, that visual acuity is greatly increased when the eye has only to focus light of a small range of wave-lengths—approximately monochromatic light. Thus it is found that for many purposes the light given by the mercury arc enables the eye to discern differences and details which quite escape it in even the best sunlight.

The large area of the Cooper-Hewitt tube takes it out of

the law of inverse squares. A bank of tubes placed side by side or otherwise distributed produce a light of approximately uniform strength all through the lighted space. The same applies to a great extent to a single tube, if the space lighted by it is not too large, or if the tube is not too remote from the observer. This fact is one of its great features of superiority over the ordinary artificial light of small area. Its operation produces an approximation to the uniform strength of sunlight. The latter, owing to the distance of the sun, is also outside the law of diminution of intensity with distance. Taking the Cooper-Hewitt lamp as a line, for small distances its light should vary inversely as the distance.

Potential Drop in the Cooper-Hewitt Lamp per unit of length of arc or of tube depends upon the pressure of the mercury vapor. The pressure in the glass tube lamp is about one-eighth inch of mercury. Its intrinsic brilliancy is so low that it can be looked at directly without disagreeable effect upon the eye, and approximates to the "cold" light of the firefly. The light given per inch length of tube is small, and the total is made sufficient by the length of the tube. In the quartz lamp, with short tube of heat-resisting quartz, the pressure of the mercury vapor may exceed that of the atmosphere, and the drop of potential per unit of length may be thirty times as great as that of the glass tube lamp. A 700 candle power tube on a 110 volt circuit will pass a current of 3.5 amperes, giving 385 watts total expenditure of energy, at 0.55 watt to the candle power. The tube is supposed to last 2,000 to 3,000 hours, although there are records of as high as 5,000 hours' burning.

Data of Cooper-Hewitt Glass Tube Mercury Vapor Lamp

Length of Tube over all..............	55½ inches
Length of Portion of Tube giving Light..	50 "
Diameter of Tube	1 inch
Mean Spherical Candle Power	670 to 850 candles
Watts per Candle Power	0.51 to 0.52
Power Factor ....about	50%
Total Watts	350 to 430
Average Life of a Tube.........about	7,900 hours

Lengths of Tubes.	Average mean spherical Candle Power.	Average Watts.	Watts per Candle Power.
21 inches	200	102	0.64
45 "	700	385	0.55
50 "	800	385	0.48
(Alternating Current)			
50 inches	800	400	0.50

Cooper-Hewitt Quartz Tube Lamps.—The use of the oxygen blowpipe, especially with acetylene or blau gas, makes it possible to work with quartz as under the ordinary air blast flame with glass. White hot quartz in a pasty condition can be plunged into water without cracking, and in general is immune to all ordinary heat, much more so than glass. It is used for mercury vapor lamps of high intensity, where a glass tube would succumb to the intensity of the heat. Quartz also permits the passage of the ultra-violet rays of light; for some purposes this is desired, as in the treatment of oils. Quartz softens not far from 1385° C. (2,500°—F.), or rather does not soften below that temperature. The potential drop in a mercury arc varying with the pressure of the vapor, and the intrinsic brilliancy and temperature varying with the same factor, the quartz tube lamp is made to operate at a pressure above that of the atmosphere, the potential drop per unit of length of arc is thirty times as great as in the glass tube lamp, and the heat is very great; it is thought that it is one of the highest heats produced by man.

Construction of Quartz Tube Lamp—The tube is about one-half inch in diameter and five inches long. At each end is a bulb or enlargement. A quantity of mercury is contained in the tube and the space above it is filled with mercury vapor. This suggests a vacuum, but in operation the heat destroys the vacuum as long as the arc exists, by volatilizing the mercury. The tube is carried in a pivoted support. If the tube is kept in a horizontal position the mercury will lie in a thin column or thread along its entire length. It has sealed-in electrodes or terminals at each end, and the thread of mercury connects these in the position assumed. If a current is turned on the

mercury will short-circuit the vapor in the tube. When the current is turned on, if the tube has its position changed so as to break the short-circuit, then the mercury-vapor arc starts and is maintained as long as the tube holds its open circuit position. There are two systems for effecting the lighting. In one the tube is kept in the closed circuit position when

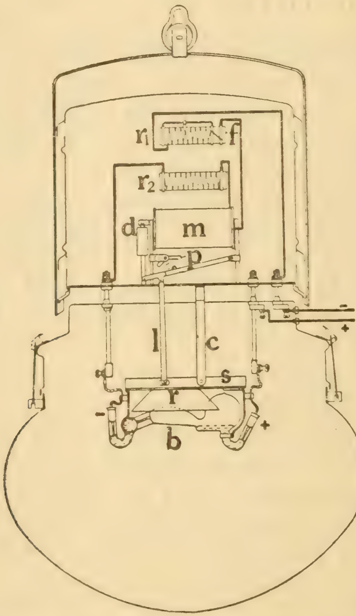


FIG. 570.—COOPER-HEWITT QUARTZ TUBE LAMP.

there is no current passing. When the current is turned on in order to light it, an electro-magnet in circuit with it is excited, attracting its armature, which is connected mechanically to the tube. The end of the tube is drawn up, the mercury thread is broken, and the mercury vapor arc is started and continues as long as the current passes.

In the cut *b* is the tube fastened to a plate, *s*, the latter carried by a pivot at the end of the supporting bar, *c*. *m* is

the electro magnet. When it attracts its armature it draws up the rod, *l*, swinging the left end of the tube upwards and breaking the mercury thread. A dash-pot, *d*, prevents any shock. r_1 and r_2 are two resistance coils, the former provided with a sliding resistance connection. The rod, *p*, operates to bring the dash-pot into operation and is in parallelism with

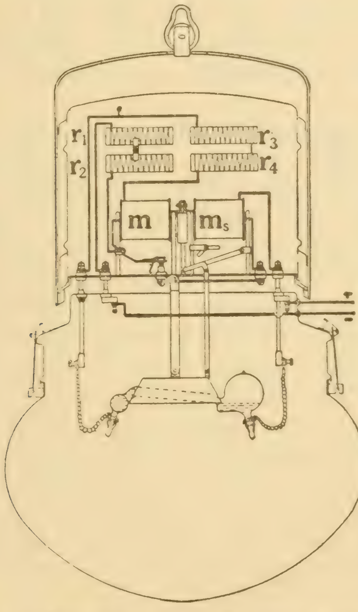


FIG. 571.—COOPER-HEWITT QUARTZ TUBE LAMP.

the support, *c*. There is a permanent magnet, so arranged as to operate a catch to hold the tube in the open circuit position, if any reversal of current should operate to drop the tube and short-circuit the vacuum. A reflector is indicated immediately above the tube.

In the next cut the other arrangement is shown. Here there are two electro magnets, *m* and *ms*. The tube is normally on open circuit so that no current can pass through it. The cir-

cuit of the regulating and lighting apparatus is closed through the two magnets, the magnet, *m*, being in shunt. When the current is turned on, the magnet, m_s, is excited and attracts its armature, drawing the tube into such a position as to close the circuit by the mercury flowing along its bottom. At once the other magnet, *m*, attracts its armature, which operates a switch to cut the shunt magnet out of circuit. The tube drops back to its open circuit position, the arc is started and the lamp works as long as current passes. Resistance coils, r_1, r_2, are indicated, and the magnet, *m*, operates as an inductance if such is required.

Action of the Quartz Tube Lamp.—In this is involved the starting characteristic and the stationary characteristic.

Starting Characteristic.—When the current starts through the cold tube the voltage of the circuit is taken up in greater part by the resistance coil in series with the lamp. On a 220 volt circuit a cold lamp will show a potential drop of only 25 volts. As the heat inside the tube increases, the voltage increases quite slowly; at the end of eight to ten minutes it reaches its maximum, about 165 volts. The current starts at about 11 amperes, slowly decreasing as the voltage increases, until it reaches, in about 11 minutes, its normal value of about 3½ amperes. The appearance of the arc changes during the lighting. At first the whole tube is filled with the arc, resembling the glass tube lamp in operation. As it attains its working temperature the arc concentrates in the middle of the tube in a thin dazzling path, losing its pale bluish color and becoming whiter.

Stationary Characteristic.—The heat capacity of the quartz tube is considerable, and this introduces a lag between the electric current changes and the burner voltage. This lag brings about the peculiarities of the starting characteristic. The voltage and current changes are due to the changes in vapor pressure varying with the heat of the tube. When the lamp is regularly operating, after its proper amperage is reached, a variation in voltage hardly affects the current at all. If at 80 volts the current is 3¼ amperes, then at 165 volts it will be only 3½ volts. Recurring to the starting char-

acteristic, some of its features are involved in a sudden change of voltage. If it is an increase, the current at first increases; the heat of the tube gradually rises, cutting down the current, which soon is reduced to its original value, although the increased voltage is maintained.

All that has been said refers to a 220 volt lamp. If the voltage on the line is suddenly decreased, the same changes take place, but in reverse order. The same phenomena attend the operations of lamps at other voltages.

Ultra-Violet Rays in Quartz Tube Lamps.—The quartz tube lamp is very rich in these highly actinic rays. They are sometimes desirable, in some chemical processes, for instance, but for ordinary lighting purposes they are not wished for. At close range they act like a strong sun or even more intensely, affecting the skin just like sunburn. The interposition of a glass shade cuts off a quantity of the ultra-violet rays so as to make the light comparatively innocuous, but depriving it of its actinic quality, something which in many cases is desirable or required. If used in the open air for lighting large areas a hemispherical globe is used, more to protect it than for the elimination of ultra-violet rays, for the air acts to eliminate them. To get the full actinic effect of the light, it should be placed close to the surface to be acted on.

Data of Quartz Tube Lamps.—The following table gives some of the principal data of the quartz tube lamps. It will be noticed that there is a large loss of voltage between lamp and line. For the 550 volt circuit, this loss runs as high as thirty-five per cent of the line voltage.

Nominal supply or line voltage	110	220	550
Full range of supply voltage..	100–125	200–250	450–625
Average current	3.8	3.3	2.0
Maximum burner voltage.....	90	170	345
Candle power mean hemispherical with clear glass globe..	1,000	2,400	3,500
Commercial efficiency, watts per mean hemispherical candle at nominal line voltage.	0.42	0.30	0.31

For each voltage a special lamp is used.

The lamp gives 1,000 to 2,600 candles at ¼ watt per candle power, which referred to the voltage of the tube reduces to about 0.40 watt.

The Mercury Arc Lamp for Alternating Currents has two positive terminals connected to the ends of a transformer. The negative lead is connected to the middle of the same transformer through an inductance and a ballast resistance. The current alternates between the two electrodes on the positive end, so as to be always in the same direction. The lamp acts as a rectifier, changing the alternating current into a direct one.

The McFarlan Moore Vacuum Tube Lamp.—This is a Geissler tube, charged with any desired gas, according to the character of light desired, operated by alternating current. The actual vacuum is 0.19 millimeter of mercury, and the variation in the vacuum must not exceed 0.01 millimeter, which is 0.00001 atmosphere. In operation the vacuum tends to increase and this is provided against by a valve operated by the primary current, which actuates the transformer, which operates the tubes. The tubes are made in section, each one 8 feet 6 inches long, and soldered or melted together. This operation is done with remarkable rapidity, two minutes sufficing for a joint. The tube when joined up may be 220 feet long. The glass is 1/16th inch thick.

The tubes operate on an alternating current circuit. The current comes from the secondary of a transformer, and is normally about 24 amperes. The vacuum rapidly increases and as it does so the current also increases, and small changes in the vacuum produce enormous changes in the resistance. Thus at 0.11 millimeter vacuum a current of 24 amperes may pass; at the end of a minute the vacuum will have increased and a current of 25 amperes will pass. At this point a valve will operate and will admit a little gas to restore the proper conditions. A candle power of 10.5 candles per lineal foot is assigned to the tube with an expenditure of 1.50 to 2.84 watts per candle power.

The automatic gas valve admits gas when the vacuum increases. A glass tube connects the gas supply to the interior

of the large lighting tube. This gas tube is closed by a diaphragm of carbon. On top of the diaphragm is mercury. Above the valve is a solenoid and armature. The latter carries a glass tube immersed in the mercury. If the vacuum increases and more current enters the lighting tube, a greater

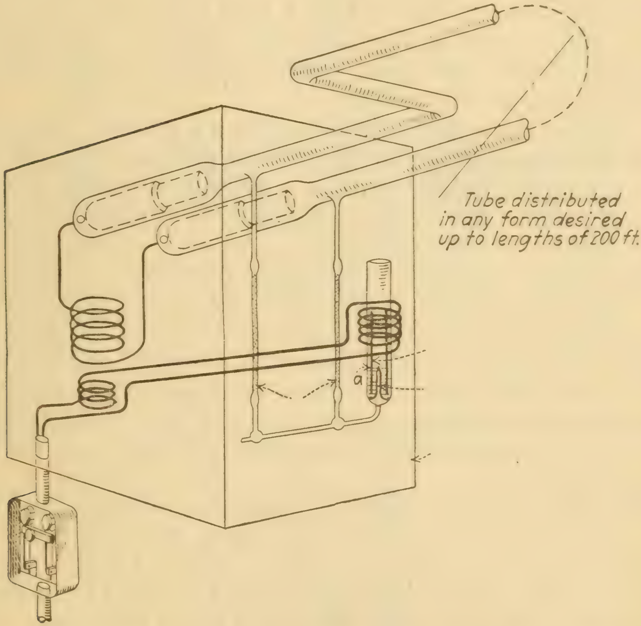


FIG. 572.—MCFARLAN MOORE VACUUM TUBE LAMP WITH AUTOMATIC AIR VALVE.

current passes through the primary of the transformer, and consequently through the solenoid. It draws up its armature, raising the tube from the mercury and exposing the carbon. Gas flows through the pores of the carbon, the current decreases and the solenoid armature descends. This raises the level of the mercury, which covers the carbon so that no gas can pass through it. This series of operations is repeated

over and over again, so as to maintain a constant vacuum within very narrow limits.

For proper working of the Moore tubes the current should have sharp peaks to its alternations.

In a Moore tube there is a point of maximum conductivity, above or below which pressure the resistance increases. In practice the tube is operated at a lower vacuum. It follows that, if the vacuum is increased, the resistance will fall and a greater current will pass. This increase is what operates the valve, as just described.

To fill the tube with nitrogen and so get the pink color, the air supplying the tube is made to pass over phosphorus.

The maximum frequency in the current operating a Moore tube is 60 cycles per second. Every foot is supposed to give a candle power of ten candles.

Neon Lamps.—Vacuum tube lamps filled with the rare gas neon have been experimented with by Georges Claude. A very slight potential is required to cause a vacuum tube containing it to glow. In wide tubes the potential fall per centimeter is only one volt. If helium is present it is slowly absorbed by the electrodes. The presence of the latter gas is always to be expected with neon and the other rare gases of the atmosphere.

Flame Arc Lamps.—These are arc lamps of the open type, whose carbons are impregnated with a chemical salt. The invention is assigned to Bremer in 1898. In the ordinary carbon arc the greater part of the light is due to the ignited ends of the carbons; in the flame arcs about three-quarters of the light is due to the arc proper. The carbons may be arranged vertically, one over the other, as in the regular arc lamp. An inverted shallow fire clay bowl, fixed a short distance above the arc, operates to retain the gases of combustion and to retard the combustion of the positive carbon, which normally burns twice as fast as the negative one. The positive carbon is in this case placed uppermost; if the positive carbon is to be placed lowest, then it must be thicker than the upper one. A probably preferable arrangement is to use inclined carbons, arranged like the letter *V*. The angle of incli-

nation may be about 15°. With the inclined carbons a "blow down magnet," as it is called, is used. The coils of the magnet lie on each side of the carbons, well out of the path of light.

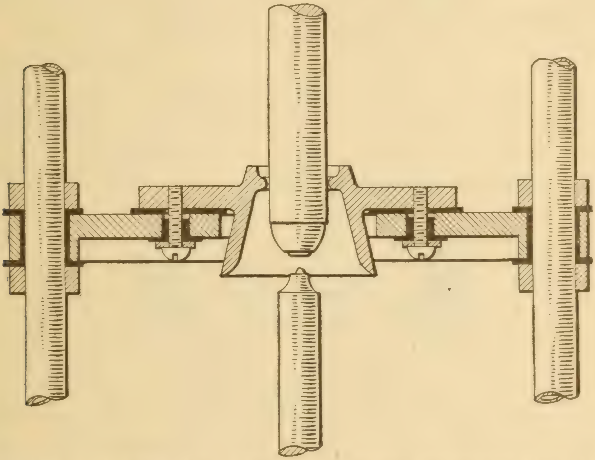


FIG. 573.—FLAME ARC LAMP SHOWING INVERTED GAS BOWL.

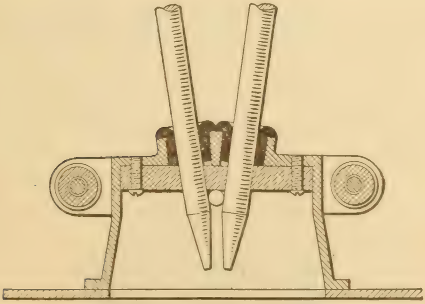


FIG. 574.—FLAME ARC LAMP WITH INCLINED CARBONS.

The core is of circular contour, lying in a horizontal plane. The poles are carried down close to the arc, one on each side. They act on the arc to drive it down to its proper position.

The length of the arc is 15 or 16 millimeters, seven or eight times as long as the carbon arc. A current of 4 amperes and a potential difference of 68 volts is standard.

The arc is so long that a special striking appliance is needed to start it when the current is turned on.

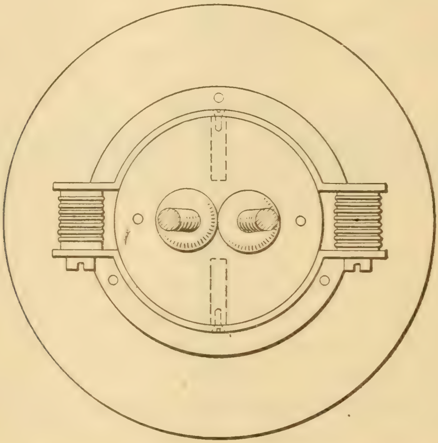


FIG. 575.—FLAME ARC LAMP WITH INCLINED CARBONS.

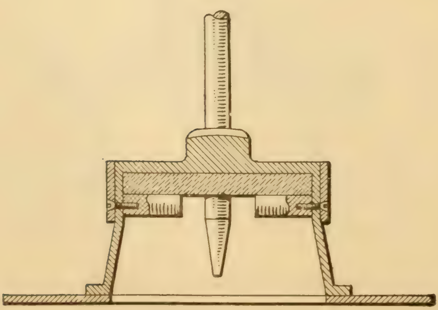


FIG. 576.—FLAME ARC LAMP WITH INCLINED CARBONS.

Blondel's Carbons have an outer zone of ordinary electrode carbon. Then comes an intermediate zone of carbon impregnated with salts, and the core is of softer carbon, also impregnated. A usual impregnating material is calcium fluoride. By the employment of different salts, different tints are obtained. To get a long period of operation, the carbons may be two feet in length.

Magnetite Arc Lamp.—This lamp, the invention of Alfred Steinmetz, has a lower electrode of copper, which is the positive one. The upper one is made of a mixture of magnetic oxide of iron and of titanium oxide, along with salts of chromium, titanium or of other metals.

Ulrich's Integrating Sphere.—This is used to determine mean spherical candle power. It is a hollow sphere, with whitened interior walls, and it is provided with a window of milk or opal glass for observation. A standard lamp is mounted within it, in such a manner that its direct rays are screened off from the window. The brightness of the window is proportional to the light within the sphere, as it impinges on the walls thereof. The window is photometered. Then the light to be tested is introduced or lighted within the sphere and the window is again photometered. The result is the relative mean spherical candle power of the two lamps. It is not of high scientific accuracy, but is extensively used. For arc lamps it is five feet in diameter; for incandescent lamps it is two feet in diameter.

The factor or coefficient for conversion of mean horizontal candle power of an incandescent lamp into mean spherical candle power varies from 0.8 to 0.95.

Lux and Lumen.—Referring to page 564 et seq. of this book, we see that the intensity of light given by a source of inconsiderable area varies inversely as the square of the distance. To make this true the source of light must be so small that it can be considered a point. In photometry a candle flame is accepted as such, although it has size and is by no means a point. The intensity of light produced by a candle at a distance of one meter is called a lux. This unit is also called a meter-candle. If this intensity is referred to

a square foot we have a unit of quantity of light called a lumen. It is a conglomerate unit, a mixture of the English and metric systems, and is used in engineering work and in cases where the illumination of areas is to be considered.

Another lumen, and a more consistent one, is the foot-candle lumen. This is the light given by a candle at a distance of one foot from the illuminated surface and distributed over one square foot area.

Steinmetz defines the lumen as the unit of light-flux, the light-flux passing through unit surface at unit light-flux density. One candle intensity of light at uniform distribution gives 4π lumens. This is because the area of a sphere is equal to the square of the radius multiplied by 4π, or to four great circles, and 4π is the area of the surface of a sphere of unit radius. Another way of expressing it is to say that one mean spherical power is equal to 4π lumens.

The unit of flux is the candle-lumen, $\frac{1}{4\pi}$ of the total light-flux from a source of one mean spherical candle power. One lumen per square meter is sometimes called the lux or meter-candle.

Utilization Efficiency.—This is a figure derived from the circumstances of each particular case, depending on the color and reflecting power of the walls. Suppose that it is required to light a room with a total of C lumens per square feet of area. The net lumens needed would then be the product of C by the area of the room, which area we may call A, so that A C would be the net lumens needed. But owing to the fact that there is inevitably a loss of efficiency, as no wall can have a 100% reflecting coefficient, the utilization efficiency is less than unity in value, and the total lumens required are expressed by the fraction, $\frac{A\ C}{E}$, in which E is the coefficient of utilization efficiency. Then if this expression be multiplied by the reciprocal of the lumens of a single lamp, we will have the number of lamps required. Calling the lumens of a

single lamp, L, and carrying out the above multiplication, we have:

$$\text{Lamps required} = \frac{A\ C}{E} \times \frac{1}{L} = \frac{A\ C}{E\ L.}$$

As this efficiency coefficient is entirely practical, there is no scientific accuracy in such calculations, since the data have to be determined by practical observation for each case. The color of the walls, their texture, roughness or smoothness and similar factors determine the coefficient.

Intrinsic Brilliancy.—If we know the era of a surface-giving light, and divide its candle power by its area, the quotient is its luminosity per unit area and is called its intrinsic brilliancy. The intrinsic brilliancy of various sources of light is given in the table, principally from Ives and Luckiesch:

Carbon Arc (Crater)	84,000
Flaming Arc	5,000
Nernst Glower	3,010
Tungsten Incandescent, Nitrogen filled....	2,200
Tungsten Incandescent (1¼ Watt C.P.)...	1,600
Carbon Incandescent (2½ Watt C.P.)....	400
Welsbach Mantle	31
Cooper-Hewitt Tube Lamp	14.9
Kerosene Flame	9

The general practical rule is that the most acceptable lights are those of lowest intrinsic brilliancy. The Student Lamp, with kerosene oil as its fuel, is often referred to as the best reading light, and kerosene is at the foot of the list. Yet the sun is of very high brilliancy and is the perfect luminary, in spite of this fact. Its perfection is largely on account of its distance, taking it out of any law of ratio of light to distance; its distance causes perfect uniformity of illumination. In artificial light an approximation to uniformity is obtained by using a number of lights and by having the walls of our rooms so treated that they reflect a quantity of light. A room with light-colored walls is better illuminated by a given artificial light than one with dark walls.

CHAPTER XLIV.

ELECTRIC FURNACES.

Electric Furnaces.—These furnaces are divisible into two principal classes, those which heat by incandescence and those in which the arc is the heating agent. Except for special uses, it is fair to say that the arc furnaces are in more general use. In the steel and iron industry there is every advantage in keeping the metal from contact with a more or less impure fuel, and this is one great advantage of the electric furnace. In general terms it may be said that the furnace is limited in size by the possible size of the electrodes. One great point in these is that they should be of as poor heat-conducting quality as possible. As they pass through the walls of the furnace without the possibility of avoiding some leakage of the gases around them, there is a tendency for them to burn or waste away outside of the furnace. This is guarded against by sheathing them with metal or by some other simple arrangement. To insure even consumption of the carbons the current is alternating and it has a power factor of 0.80 to 0.83. A seven and a half ton furnace may have 12-inch graphite electrodes, with a current of 10,000 amperes and a potential of 80 volts. Taking it as operated at two phases, we have for the power absorbed:

$$\frac{2 \times 10{,}000 \times 80}{0.8 \times 1{,}000} = 2{,}000 \text{ kilowatts.}$$

Electric Steel Furnaces.—The diagrams illustrate the principal types of electric furnaces used in the manufacture of steel. The Heroult furnace is simply a closed hearth furnace, through whose roof the carbon electrodes project,

being fed down as fast as they are consumed. Alternating current is supplied from a transformer, which gives the proper voltage as determined for each case; arcs are struck and continue to exist as long as the current is supplied. The steel is melted absolutely out of contact with anything except the furnace walls and bottom and any flux or other ad-

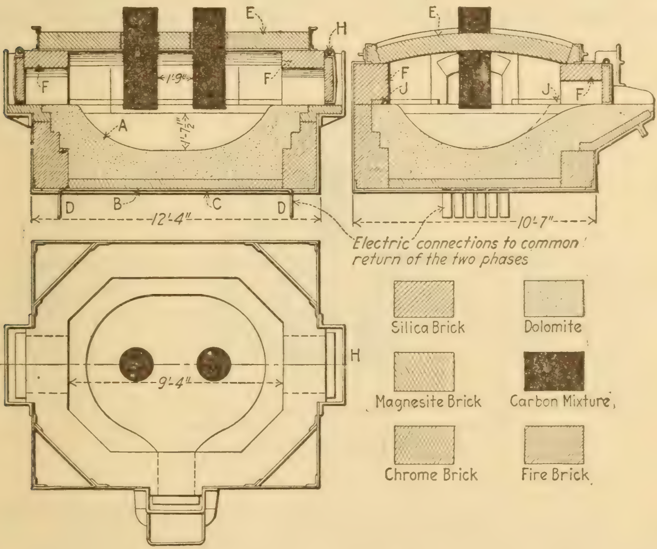


FIG. 577.—HEROULT FURNACE.

dition purposely made. It is as pure a type of arc heating as any.

The Girod Furnace, operated by a monophase current, is shown next. The arc goes from upper electrode to the charge proper, the latter being in electric contact with the lower electrodes, which extend through the bottom of the furnace. The next cut shows the same furnace for three phase current. In it the arcs are produced between the upper carbons, while the lower ones, connected as indicated, operate as the neutral point.

Girod Furnaces in Bethlehem, Pa.—The following is the description of the Girod steel furnaces being installed at the Bethlehem Steel Works. They are cylindrical in shape, 15 feet in diameter and 5 feet high, with shells of ¾-inch steel plates. The whole structure is mounted on rockers, so that it can be tilted to pour out the charge. The bottom of the hearth is 14 inches thick, of dolomite or magnesite. The metal bath on top of this is 14 inches deep. Fourteen water-

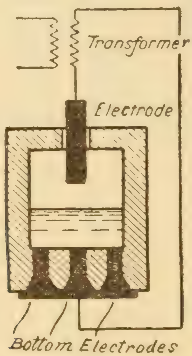


FIG. 578.—GIROD FURNACE.

cooled steel electrodes connect the bath electrically with the bottom shell of the furnace. The top or roof is of 9-inch silica brick, separated from the hearth by asbestos. Three electrodes enter through the top; each one is 18 inches in diameter, with a working length of 6 feet. They are carried in copper holders, which are water-cooled. They are raised and lowered by a motor, so as to keep them at a standard distance of 4 inches above the surface of the melted steel. The furnace weighs about 90 tons. It operates at 1,500 kilowatts, 3 phase and 25 cycles at 65 to 85 volts, the carbon electrodes taking two phases, with the shell of the furnace connected in the neutral point. 2,500 kilowatt, 6,600 volt 25 cycle generators are employed. There are three oil-cooled transformers for each furnace protected by reactance coils.

Of 700 kilowatts leaving the transformers, 620 are absorbed through the electrodes.

The Kjellin Furnace is a purely inductive one. In the diagram is shown a heavy core of rectangular shape, around one of whose sides a coil of wire is placed. The opposite side is surrounded by a circular trough-like hearth for the steel. If an alternating current is passed through the coil, the current induced in the metal in the trough heats it to any desired degree within the capacity of the apparatus. A rotary segment at the top of the core is supplied with direct current, and rotates under the effect of the alternating current and is designed to increase the efficiency of the electric operation. One of the problems is the starting of this type of furnace before the charge has become conductive. One method is to introduce an iron ring extending around the hearth, which heats up under the induced currents and brings the charge to fusion, when the charge makes a connection of itself and the operation goes on normally.

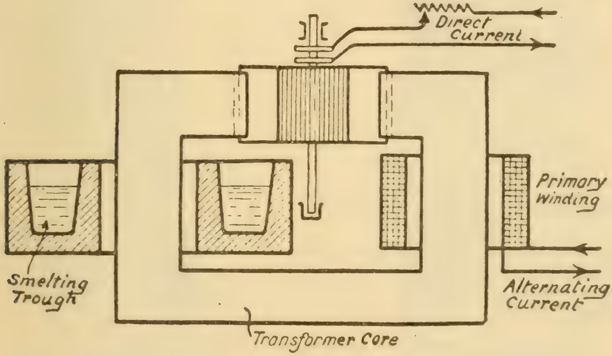


FIG. 579.—KJELLIN FURNACE.

The Roechling Furnace heats its charge by conduction through the metal itself. The cut is self-explanatory. The current induced in the secondary passes through the length of the charge as it lies in the hearth, the metal in the hearth

forming a portion of the secondary of the induction coil which is constituted by the construction of the furnace.

A Swedish Shaft Furnace is next shown. This is a single arc furnace of the cupola or blast furnace type.

A Hering Ore Reducing Furnace is the next illustrated. This heats by conduction, and as the charge is reduced to the

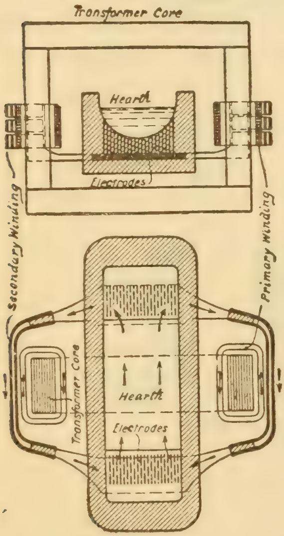


FIG. 580.—ROECHLING FURNACE.

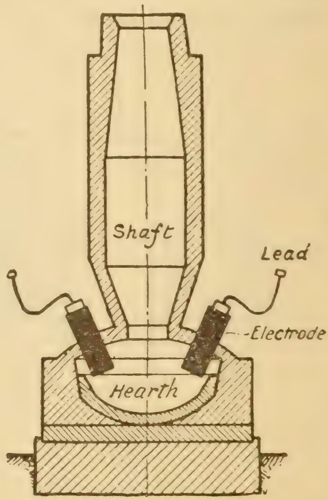


FIG. 581.—SWEDISH SHAFT FURNACE.

metallic and fused state it is withdrawn from time to time through the tap hole.

The cut of the Hering combined ore reducing and steel furnace is also self-explanatory. The left-hand furnace is a simple melting furnace and next to it a melting furnace of identical construction, into which the metal from the reducing furnace flows and is subjected to any additions of alloys or to any desired refining or treating process desired.

Aluminum Furnace.—The Heroult furnace, shown on page 778, for the production of metallic aluminum, has a massive

iron casing. It is, in recent practice, made hollow so as to be water-cooled. At *E* it is connected to one of the electric leads. It has a refractory lining, *B*, and at *C* is a mass of aluminum or copper, which is in electric contact with the shell or casing of the furnace. *H* represents the carbon anodes. The material operated on is purified aluminum oxide, mixed with cryolite; the latter is sodium-aluminum

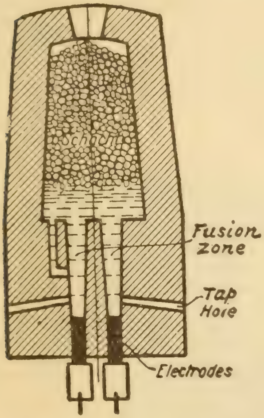


FIG. 582.—HERING ORE REDUCING FURNACE.

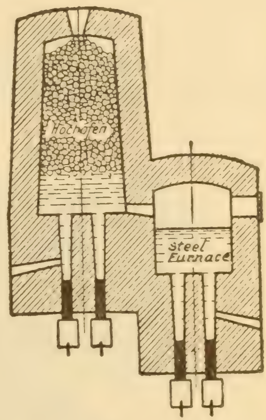


FIG. 583.—HERING COMBINED ORE REDUCING AND STEEL FURNACE.

fluoride; it is easily fusible and when fused is a solvent for the oxide. After the furnace has received its charge, an arc is started by bringing anode, *H*, and cathode, *C*, into momentary contact; on drawing them apart the arc forms and melts the central portions of the charge. The current is unidirectional, so there is not only the intense heating effect of the electric arc to melt the cryolite and cause the solution of the oxide, but electrolytic decomposition of the dissolved oxide is started and metallic aluminum is produced and runs down through the charge and adds itself to the metal in the bottom of the furnace. As the charge is exhausted more is

added through the top as required. The metal produced is drawn off at the tap-hole, *F*.

Carborundum and Graphite.—Carborundum is a chemical compound of carbon and silicon, *C Si*. It is a powerful abrasive and has largely supplanted natural emery. It is used in powdered form and as grinding wheels and other shapes. The furnace in which it is made is an extremely simple one. It is a receptacle of trough-like form, about 15

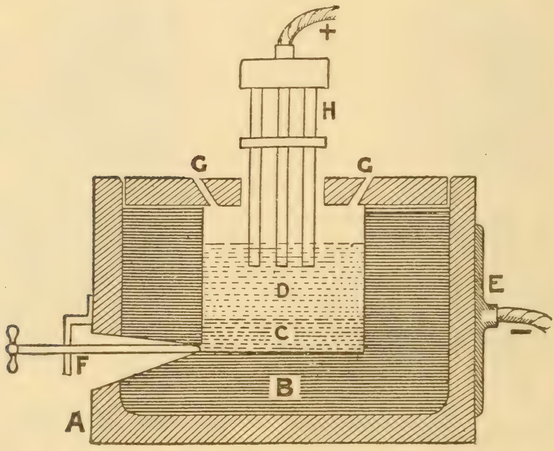


Fig. 584.—Heroult Aluminum Furnace.

feet long and 7 feet high and wide. It is made of bricks, laid up dry. *C* and *C* are carbon electrodes connected at *B* and *B* to the electric circuit. It operates by incandescence mainly. For this furnace a charge of ten tons is required, consisting of about the following mixture: Coke, 34%; Sand, 54%; Sawdust, 10%; Salt, 2%. In putting in the charge, as the level of the carbon electrodes is reached, a core of coke 9 feet long and 2 feet thick is placed horizontally, so as to connect the electrodes electrically and give a path to start the current. When the furnace is in operation and intensely hot all of the charge is highly conductive. When cold it is

non-conductive. On turning on the current the heat slowly grows and for two hours large quantities of carbon monoxide are evolved and burn all over the outside as the gas escapes through the crevices of the brickwork and elsewhere. In twelve hours the whole furnace and charge is red-hot. After a run of twelve hours the current is turned off and the mass is allowed to cool. Four thousand amperes at 185 volts are used; the current is alternating. The mass is annular or ring-like in distribution. The outer layer is insufficiently converted and is saved and goes into another charge, so as to get a second treatment. Next comes a sixteen-inch layer or cylinder of true carborundum. This is the desired product.

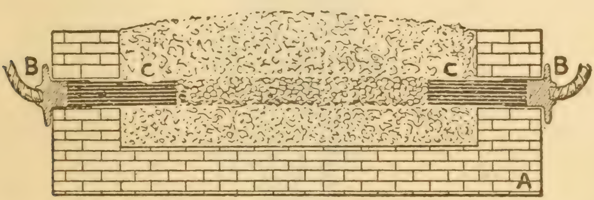


FIG. 585.—ATCHESON'S CARBORUNDUM AND GRAPHITE FURNACE.

The central core is graphite, also a merchantable product. The carborundum is ground and made into the various products as required.

Each group of electrodes comprise 60 carbons, each one 3 inches in diameter and 2 feet long. About 50% of the theoretical yield of the carborundum is obtained.

Calcium Carbide.—This substance is interesting, as it represents the first success ever attained in the synthesis of carbon and hydrogen, in which its production is the first step. Its formula is Ca C_2. A three phase small shaft furnace is shown in the cut. At *A* is a cast-iron disc, whose upper surface is protected by a layer of graphite. This disc can be lowered to the bottom of the furnace by the screw, *B*, operated by the hand wheel on top of the shaft, *C*. The arc is started with the plate just in contact with the carbons; con-

tact is at once broken and purified lime and coke, which make up the charge, are slowly poured in after the arc is started. The heat is intense and it causes the combination of carbon and the calcium of the lime, and as fast as this takes place the disc is lowered, and more charge is introduced. Thus when the disc reaches the bottom the shaft of the furnace is filled with calcium carbide. The product is about 90% pure.

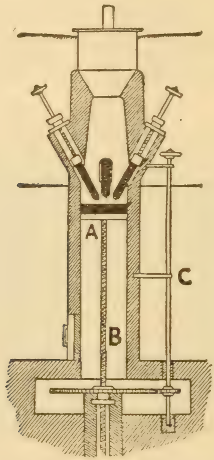


FIG. 586.—CALCIUM CARBIDE FURNACE.

Sodium Furnaces.—In the Castner process, which was about the first electrolytic method successfully used for the production of sodium, fused sodium hydrate is electrolyzed at a temperature of 325° C. (617° F.). This is a low red heat. Referring to the cut the vessel containing the melted hydrate is shown. Through its bottom the cathode *B* enters. A certain amount of solid hydrate forms around the neck of the vessel at the bottom and makes a tight joint around the cathode. The anodes, *D*, which are arranged in a circle, surround the upper end of the cathode. A tube, *F*, has a cylinder of wire gauze, *E*, at its lower end, intervening be-

tween anodes and cathode. The anodes, cathode and pot or melting vessel are made of iron. As the hydrate decomposes under the effect of the current metallic sodium goes to the

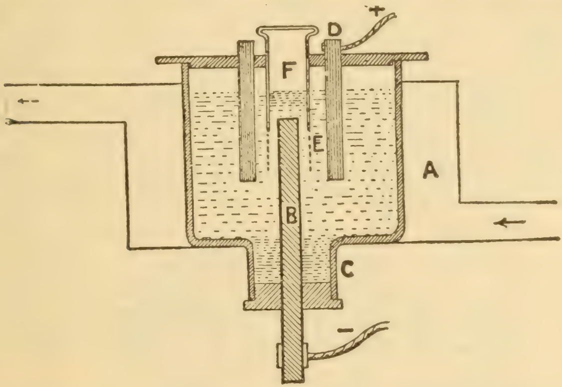


FIG. 587.—CASTNER'S SODIUM FURNACE.

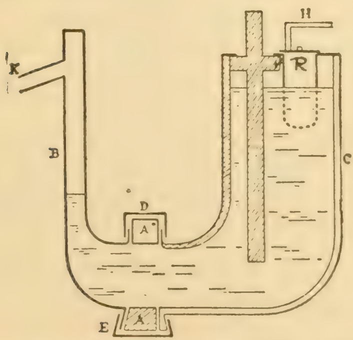


FIG. 588.—BORCHER'S SODIUM FURNACE.

cathode and collects in the tube, *F*, floating on top of the fused hydrate. From time to time it is removed by ladling it out. A horsepower of electric energy will produce about one-half ton of sodium per annum.

In the Borcher process sodium chloride is decomposed, giving chlorine and metallic sodium. The cut shows two vessels connected at their bottoms by a flanged joint with an intervening metallic ring, *A*, and clamps, *D* and *E*; it is kept tight by solid sodium chloride which forms about it. The metallic ring is cooled so as to effect this result. The vessel, *C*, is of refractory clay, and the vessel, *B*, is of iron; the latter forms the cathode, and the anode is seen passing through the top part of the vessel, *C*. When the current passes it decomposes the salt, the sodium collects in *B*, floating on the surface of the melted salt, and as it accumulates it overflows through the outlet, *K*. Chlorine is evolved in *C*; this is drawn off through the pipe, *H*. As the salt is decomposed more is added through the opening, *R*; it falls into a perforated vessel, and melts. The lower end of the tubular vessel in question is immersed in the melted salt, so as to trap off the chlorine.

In the Castner process there is a certain amount of oxygen and of hydrogen produced. The oxygen is saved, constituting one of the useful products; in the Borcher process the chlorine is also saved as a valuable side-product.

Fixation of Atmospheric Nitrogen.—This is effected in electric arc furnaces by passing a stream of air through the greatly enlarged arc. In one kind of furnace the arc is flattened out and greatly extended by a strong magnetic field; in another the air treated in the furnace is made to expand or lengthen the arc. The chemical reaction gives nitric oxide, N O, which in the presence of water gives nitric acid, thus:

$$2\,NO + 3\,O + H_2O = 2\,HNO_3$$

The reaction is given in its simplest form; it is really made up of intermediate steps.

Electrodes in these furnaces are made of metal; different metals are used, the selection being made of such as wear away slowly. The potential difference is very high, it may be several thousand volts, so that very good insulation is required. As there is no solid substance in the furnace, no slag or melted metal, the furnace lining lasts much longer

than in an ordinary metallurgical furnace. The stopping or starting of such furnaces is not much more of an operation than in the case of an ordinary arc lamp.

In the Brickland Eyde furnace the electrodes are quite close at their ends, about 0.3 inch separating them, but a strong magnetic field which surrounds them repels and flattens out the arc to comparatively large dimensions. One arc after another is described as driven out radially in great semicircles. A 50 cycle alternating current at 10,000 volts, reduced to 5,000 volts, is employed. As the arc is acted on

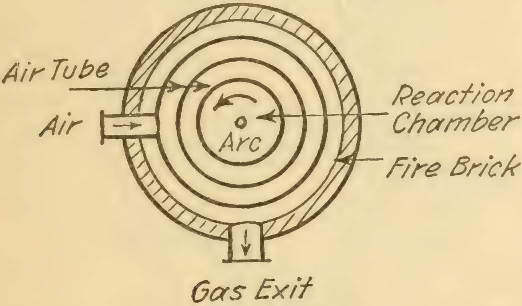


FIG. 589.—CROSS-SECTION OF THE SCHOENHERR NITROGEN FIXATION FURNACE.

by the magnetic field its potential rises across the electrodes, and air is blown through the chamber in which the arcs are produced. The nitric oxide is withdrawn as fast as it is produced, because it would dissociate again if left in the furnace too long. Its temperature as it is withdrawn is about 1,250° C. (2,282° F.) One kilowatt-hour gives 67 to 70 grams of nitric acid.

The Schoenherr furnace is a tubular structure; the arc produced in the lower end of a vertical tube is lengthened out by the inrushing air to a length of 23 to 25 feet. The tube in which the arc is produced is of iron, and constitutes one of the electrodes. The air is made to take a tangential or spiral path, so that the arc is kept in the axis of the tube and its sides are not attacked. An alternating current at

4,500 to 5,000 volts is employed. The gases at the outlet have a temperature of 850° C. (1,562° F.) The largest size furnace uses 800 kilowatts and gives 65 grams of nitric acid per kilowatt-hour.

The cut shows the cross section of the Schoenherr tubular furnace. The air is preheated in the annular passages be-

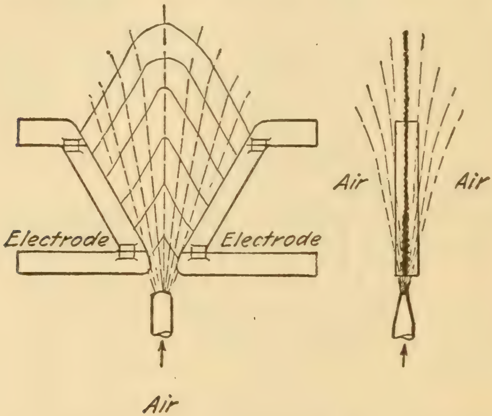


FIG. 590.—THE PAULING NITROGEN FIXATION FURNACE.

fore entering the central tube containing the long arc. Seventeen per cent of the heat is lost by radiation, and about 30% by the water used for cooling the electrodes.

The diagram of the Pauling furnace illustrates the shape of the electrodes and the contour of the arcs formed between them as they are drawn out by the inrush of air. The ends of the arcs are described as moving along the surfaces of the diverging electrodes in a succession of little leaps, the arc being momentarily held at each point until the air blast drives it on. The electrodes last a long time under the conditions obtained, as their surfaces are comparatively large. In furnaces using electrodes, from whose ends the arc starts, the wear is much greater.

A modification of the Pauling furnace is shown in the next diagram; it is due to Phaeler and Heckenbleckner. Movable

electrodes, called kindling blades, are used to start the arc. The electrodes are cooled at the base only. There are two air supplies; one at high pressure cools the starting blades; the greater portion of air is admitted at low pressure after it has been preheated. Some of the gases from the outlet of the furnace are blown in through cooling ducts. These gases

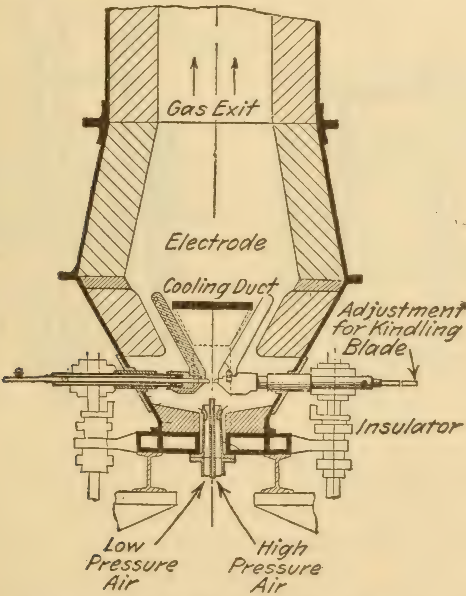


FIG. 591.—PHAELER AND HECKENBLECKER NITROGEN FIXATION FURNACE.

are identical in composition with the freshly treated gases, and they operate to reduce the temperature so as to prevent dissociation of the newly formed nitric oxide.

The J. S. Island furnace has V-shaped rings, as shown in the illustration, the central one rotating. Air enters through holes in the angles of the stationary outside rings. The central ring rotates rapidly, carrying with it, as it were, the arc, which presents the appearance of a ring of fire, although it

is only a single arc. The air holes in this construction are said to burn out rather rapidly.

The Moscicki furnace is shown in diagram. One electrode is seen passing up from the base of the furnace in its axis;

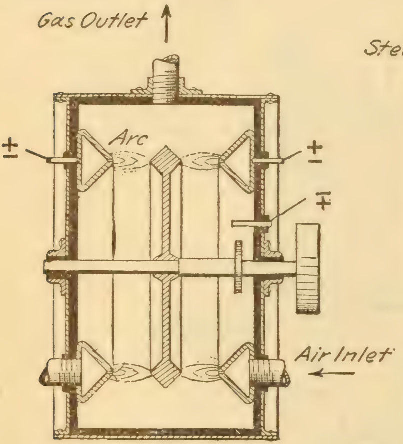


Fig. 592.—J. S. Island Nitrogen Fixation Furnace.

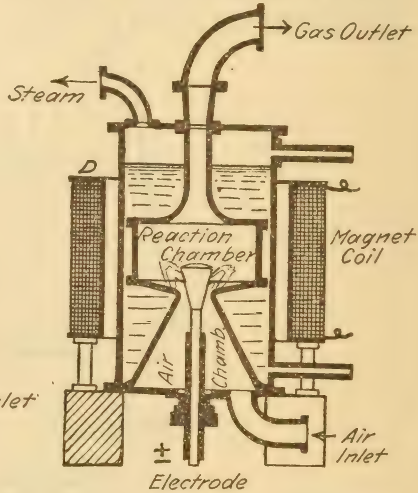


Fig. 593.—Moscicki Nitrogen Fixation Furnace.

the other electrode is formed by the casing, indicated by the heavy black lines. Arcs spring from the conical top of the central electrode in a radial direction, and the magnetic field due to the coil seen surrounding the furnace keeps the arc or arcs in rotation. The casing is cooled by water-jacketing.

The power factor in these furnaces is from 65% to 70%. The nitric oxide is absorbed by water in a tower or proper mixing structure.

Air Supply for Nitrogen Fixation.—In all these furnaces the air should be as pure as possible, dust particles, oil or moisture and the other impurities in air impairing the results obtained. By direct experiment it has been found that the yield on moist days is inferior to that obtained on dry days.

CHAPTER XLV.

ELECTRIC BLEACHING.

Electric Bleaching involves the decomposition of a solution of sodium chloride by electrolysis, under conditions which insure the liberation of chlorine as the bleaching agent or the formation of hypochlorite, a powerful bleaching salt.

If a solution of sodium chloride is decomposed by a strong electric current at high voltage, sodium hydrate goes to the cathode and chlorine to the anode. This accounts for the sodium chloride and for one hydroxyl group of a water molecule for each molecule of sodium chloride. The remaining atom of hydrogen escapes from the surface of the cathode as a gas. The reaction is the following:

$$Na\,Cl + H_2O = Na\,O\,H + H + Cl.$$

To decompose sodium chloride requires a potential difference of 4.2 volts. One horsepower hour gives 232.92 grams or 73.5 litres of chlorine. Of course, in practice there is a considerable loss, and such figures as the above are not realized.

In the original Kellner process the sodium chloride solution is kept in circulation by a rotary pump, between electrodes wound with platinum-iridium wire. As the current passes, the solution grows stronger, and when its strength is sufficient the current may be stopped and the solution of sodium hypochlorite is withdrawn.

In the Haas and Oettel process a stoneware vat has vertical electrodes which act as partitions and divide it into compartments. There is an orifice in the bottom of each compartment and an overflow at the top. The vat is called the electrolyzer. It is placed in a stoneware tank, considerably

larger than itself, so that there is a space between the walls of the two vessels. Salt solution poured into the outer vessel rises through the electrolyzer, nearly to the level of the overflow. The current is turned on, the solution froths up as it is decomposed, and overflows into the outer vessel. Solution enters at the bottom to make up for what passes out, and thus a constant circulation is kept up, and the operation is continued until a proper strength of the hypochlorite solution has been attained. There is a cooling coil in the outer vessel. The electrodes are made of graphitic material and last eighteen months.

The Kellner process, improved by Foester, Siemens and Halske and others, has its anode at the bottom of the decomposition vessel. The gaseous hydrogen, the cause of the foaming of the solution, is liberated from the cathode near the top, so that the liquid in the bottom is undisturbed. Here in operation the chlorine is liberated and, reacting with the sodium hydrate also formed at the anode, gives hypochlorous acid. This is a powerful bleaching agent.

At the anode at the bottom of the vessel the reaction starts thus:

$$\mathrm{Na\,Cl + H_2O = Na\,O\,H + H + Cl}$$

The hydrogen escapes as a gas; the chlorine dissolves in the solution, which, as it diffuses upward, brings the chlorine into contact with the sodium hydrate formed at the cathode at the top of the vessel.

$$\mathrm{2\,Na\,O\,H + 2\,Cl = Na\,Cl + H_2O + Na\,O\,Cl}$$

The hypochlorous acid acted on by the excess of sodium hydrate present forms sodium hypochlorite, and this in its turn gives hypochlorous acid:

$$\mathrm{Na\,O\,Cl + 2\,Cl + H_2O = Na\,Cl + 2\,H\,O\,Cl}$$

Some lime salt and some organic matter should be present. This coats the cathode, so that there can be no reduction to sodium chloride by contact with the metal of the cathode.

The electrodes are of platinum wire gauze.

The Leclanche bleaching apparatus has carbon anodes and iron cathodes. The carbons are enclosed in a sort of inverted bell, whose sides are asbestos diaphragms, closed at the top by metal tops, whence the gaseous chlorine escapes through a tube connected to the apex. Sodium hydrate is withdrawn from the compartment outside the asbestos, where it forms at the cathodes. The chlorine is introduced into the vessel receiving the sodium hydrate and the liquid is agitated by a paddle wheel so as to mix gas and liquid thoroughly and produce sodium hypochlorite, ready for use as a bleaching liquor.

It is an object to remove the hypochloric solution from contact with the anode, in the case of the apparatus first described, as soon as possible; action of the anode on sodium hypochlorite oxidizes it to sodium chlorate, $Na\,Cl\,O_3$, which is of no value as a bleaching agent.

CHAPTER XLVI.

PUPIN'S COILS. LIFTING MAGNETS.

Pupin Coils.—Long distance telephony has been made possible, it is not too much to say, by what is called Pupinization, the installation on the line of inductances. The idea was conceived by Prof. M. I. Pupin about as far back as 1899, and it took some ten years to bring it to perfection, and it involved elaborate mathematical investigation to develop the application of the invention. A constant, called the Pupin constant, enters into the calculations.

Long lines of telephone circuits of high or moderate capacity act to damp the telephonic waves. Capacity, inductance, resistance, length of line and leakage all enter as factors in the transmission. The leakage is not especially important. If the inductance is small the enunciation is loud and indistinct, and the overtones and hissing sounds are damped. On the other hand, high inductance damps all the sound-producing waves to more nearly the same degree, and the volume or loudness of the sound is reduced. In the Pupin invention self-inductance is added at intervals all along the line. This is done by connecting coils of high inductance at determined distances to the transmission line.

The cores of the loading coils, as the self-inductance elements are called, are ring shaped for land wires, and are made of fine iron wire of specially selected iron, whose constants insure the best results. The wire is of 0.004 inch diameter; the windings are insulated from each other to reduce hysteresis. A core receives two windings, one for each side of the transmission circuit, in the directions shown in the diagram. Each coil, it will be seen, magnetizes with the same polarity, so that there is no mutual induction added

to the self-induction. The coils are immersed in an insulating compound, after being wound with tape, and are put into iron cases.

The installation of the coil in its case on a telephone pole is shown in the cut. On aerial lines there may be a coil for every 6 to 9 miles; on subterranean lines they are about five

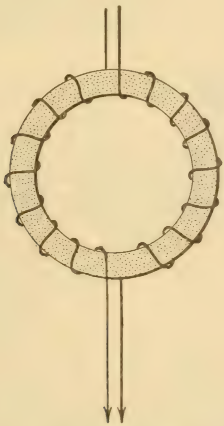


FIG. 594.—PUPIN'S COIL FOR LONG DISTANCE TELEPHONE LINES.

times more closely installed, from 1¼ to 2 miles apart, and in sea cables a sea mile is a standard distance. The disposition of a coil in a submarine cable is shown in the cut. It only involves a slight swelling or enlargement in diameter of the cable at the proper intervals.

The inductance of each coil may vary quite widely, according to requirements. A range from 0.02 to 0.2 henry is given as covering the maximum.

The coils add greatly to the length of the line. On the line from New York to San Francisco, a metallic circuit of 6,800 miles, the coils contain 13,600 miles of copper wire, which is added to the length of line.

A circuit provided with Pupin coils is said to be loaded.

On a loaded circuit the insulation must be particularly good; the best types of insulators are used on the poles and pole arms, and the bridle wires have special insulation to prevent leakage. These are the wires connecting the coils to the line, and at first much trouble was experienced with them.

The cable contains four wires. They are twisted in pairs, and then the two pairs are twisted around each other. This arrangement gives two through telephone circuits and one

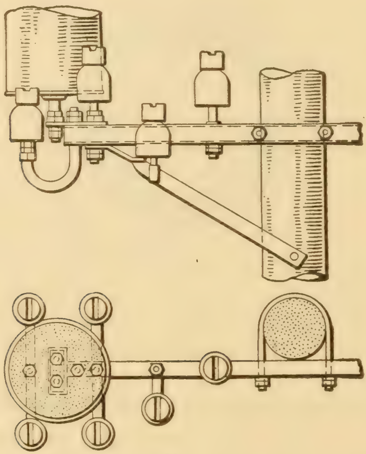


FIG. 595.—MOUNTING OF PUPIN'S COIL ON TELEPHONE POLE.

phantom circuit. Two wires make up one side of a phantom circuit, so that the phantom current goes in the same direction on both wires of the actual circuit. On the other hand, these wires have opposite currents on them, as regards the actual circuit. Eight telegraphic messages and three telephone messages can be sent simultaneously on the four wires of the cable.

The cable or group of four twisted wires, as described, is called a quad. The twisting is essential to enable them to be phantomed.

Some of the factors of the U. S. transcontinental line are given here. The electric constants are referred to the mile:

New York to San Francisco: Length miles, 3,400; resistance ohms, 4.95 per m.; inductance henries, 0.0365 per m.; capacity micro-f'ds, 0.0091 per m.; attenuation, 0.0013.

FIG. 596.—PUPIN'S COIL ON CABLE.

Lifting Magnets.—These have attained quite an extensive application in the iron and steel industry. They are simply specially constructed electro magnets, used instead of hooks and chain slings to lift iron. They are made of great power, a range of from ½ to 1½ tons being standard.

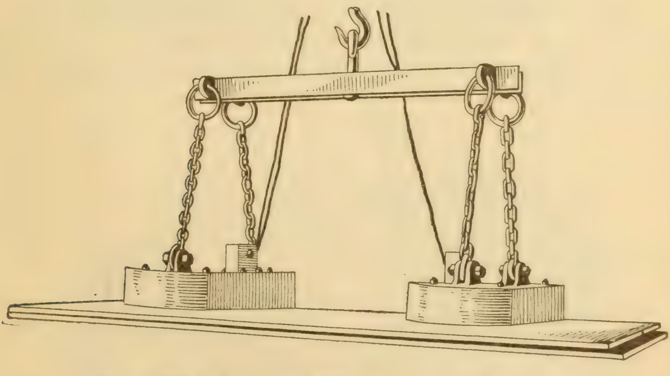


FIG. 597.—LIFTING MAGNETS IN PAIRS.

In use they are attached to the end of a lifting chain tackle. When iron or steel is to be lifted the tackle is paid out until the magnet is in contact, or virtually so, with the iron to be lifted. The iron adheres and can be lifted about and released as desired. To lift the iron the magnet is excited by a strong

current. On reversing the current the iron drops. A small magnet will lift 15 times its own weight; a magnet 2 to 3 feet in diameter will lift 8 to 12 times its weight, and a 3 to 5 foot one will lift only 5 to 6 times its weight. As many

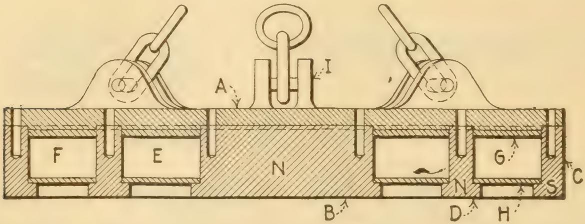


FIG. 598.—CASE OF PHENIX LIFTING MAGNET.

as six layers of plate iron can be lifted at once. By manipulation of the commutator they can be dropped off one at a time. Mica sheets are used to insulate the coils and they are protected by an insulating compound, sometimes introduced under a vacuum. This eliminates sweating and makes them waterproof.

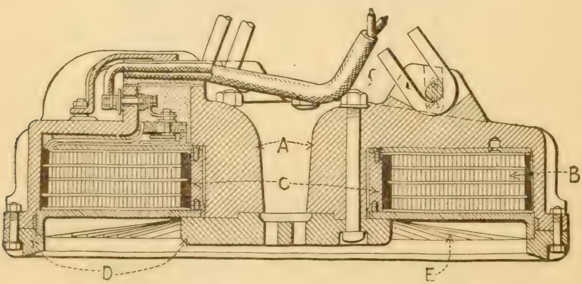


FIG. 599.—INGRANIC LIFTING MAGNET.

The Phenix Lifting Magnet has two concentric annular coils carried in a casing *AC*, one in the space *F*, the other in *E*. The poles *N* and *S* and the casing are made of high permeability cast-steel. The annular well *D* separates the coils. The

coils are wound on brass forms so as to insure rigidity, as there is a tendency in the turns of the coils to move slightly as the current is switched on and off. Plates *H* hold the coils in place and protect them from injury; these coils are made of phosphor bronze.

The Ingranic Lifting Magnet has a magnet steel body, *A*, with lifting lugs cast integral with it. The terminal box is also part of the casting. Pole shoes, *D*, are bolted to the frame or body. *E* is a flanged disk of corrugated manganese steel which protects the coils. The coil, of copper strip, is

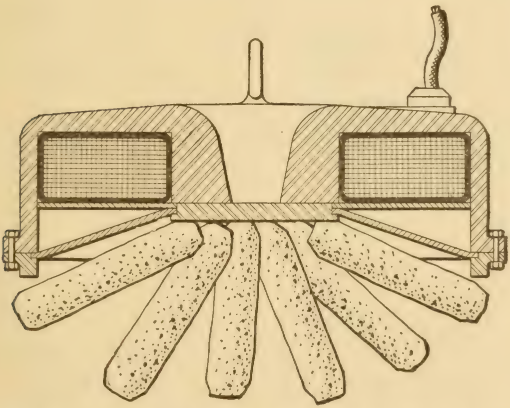


FIG. 600.—"WILTON KRAMER" LIFTING MAGNET LIFTING PIG IRON.

wound on the spool *C*. Mica insulation is used as needed and waterproof insulation is introduced under vacuum.

In shutting off the current a resistance coil is first connected across the terminals of the magnet windings, then the current is reversed and shut off. The object of doing this is to prevent a discharge current from piercing the insulation. Such a discharge would otherwise take place on account of the high inductance of the magnet.

Lifting magnets are on record as reducing the expense of unloading pig iron to one-eighth of the expense when done

by hand. Two 62-inch magnets and two men with hoisting apparatus unloaded 1,900 tons in 10½ hours, with an average lift of 1.53 ton. To do this by hand would require 48 hours' work of twenty-eight men. In another case, 55 tons of pig iron were lifted in half an hour by one 52-inch magnet, with a capacity of 0.84 ton.

The reversal of the current is to effect the detachment of the load by demagnetizing the massive core.

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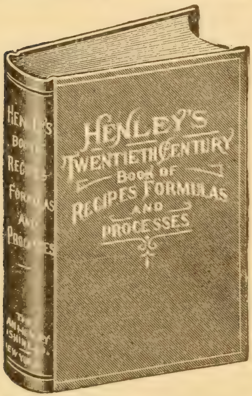

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